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THE MORRISON FORMATION AND ITS RELATIONS WITH THE COMANCHE SERIES AND THE DAKOTA FORMATION[1]

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The beds now generally designated on U. S. Geological Survey maps as the Morrison formation have been a subject of interest and discussion since 1877, when abundant remains of dinosaurs were found in them. The first extensive collections of the vertebrate fauna were obtained in the neighborhood of Morrison near Denver, in Garden Park, near Canyon City, Colorado, and at Como, or Aurora, Wyoming. Since then the formation has been recognized by means of its fossils, its lithologic features, and its stratigraphic relations in the Black Hills, on the Laramie Plains, and elsewhere in Wyoming, in Montana, in western Colorado, in southeastern Colorado, and in adjacent parts of Oklahoma and New Mexico.

Of the various names that have been applied to the formation Atlantosaurus beds is, perhaps, most frequently seen in the literature, but Como stage, Beulah shales, Morrison formation, and Gunnison formation have been locally applied. In recent publications Darton has used the term "Morrison formation" in all the areas mentioned.

The formation is non-marine throughout, so far as known, and consists of variegated marls and shales with irregular beds of sandstone and sometimes thinner layers and lenses of siliceous limestone.

[1] Published by permission of the Director of the U. S. Geological Survey.

The colors of the shales and marls are greenish-gray, purplish, maroon and red, very irregularly distributed, while the sandstones are usually gray, sometimes weathering brown or with small brown spots. The limestones are gray, in some cases weathering with a reddish tinge. The general appearance of the formation is remarkably uniform over large areas, and yet the individual elements are so variable that no two detailed sections are exact duplicates of each other. The total thickness is seldom more than 200 feet, though it is possibly more than 400 feet at Canyon City.

Stratigraphically the Morrison is always rather closely associated with the Dakota formation. When the huge Morrison dinosaur bones were first discovered it was announced that they came from the Dakota, and after it was learned that they really came from a lower horizon it was generally believed for many years that there was no unconformity nor visible stratigraphic break between the two formations. Through the work of Ward, Jenney, and Darton in the area north of Colorado the Lakota and Fuson formations have been recognized between the true Dakota and the Morrison and referred to the Lower Cretaceous. I shall presently show that in southern Colorado, New Mexico, and Oklahoma the so-called Dakota should also be divided because it includes a marine Lower Cretaceous horizon. It is nevertheless true that the base of the Dakota is usually not more than 100 to 200 feet above the top of the Morrison, and it is often less than that. Darton has recognized a general unconformity at the top of the Morrison in Colorado and eastern Wyoming, but he believes that the interval represented by it is unimportant. The base of the restricted Dakota also rests on an uneven surface wherever the actual contact has been seen.

While the Morrison formation is thus almost invariably accompanied by the Dakota, the converse is not true; for the Dakota has a much wider distribution to the east and southeast, and, in the typical Dakota area extending southwesterly from the Missouri River in eastern Nebraska to the Arkansas in Kansas, the Morrison formation does not occur. The Dakota is fairly well recognized in northern Texas near Denison, where it rests on the Comanche series, here developed to a thickness of several hundred feet. This area was doubtless originally continuous with the Cretaceous in

southern Kansas (Kiowa, Comanche, Barber, and Clark Counties), where the Dakota sandstone is separated from the Red Beds by 100 to 150 feet of Comanche shales and sandstones, representing not the whole series but probably only its upper, or Washita, group. The attenuated margin of late Comanche deposits has been recognized by means of marine invertebrates as far north as Salina, Kansas, where it rests directly on the Permian and beneath the Dakota. Its occurrence at several points in Oklahoma, and eastern New Mexico, especially at Mesa Tucumcari, has long been known, but until recently there was no evidence that Comanche sediments with their marine fauna approached the dinosaur-bearing Morrison formation more closely than several hundred miles.

In 1901 Lee announced the discovery of the Morrison formation[1] in southeastern Colorado on the Purgatoire River, and its probable occurrence as far south as the Cimarron in New Mexico. It had previously not been known east of the Rocky Mountain foothills. The following year Lee continued[2] his explorations south and east and found the Morrison on Canadian River[3] in New Mexico, as well as on the Cimarron. He also suggested its correlation with the Comanche series in the following words:

> In Mr. Hill's folio of the *Texas region* he gives a section showing the geology of the Texas region. This region embraces the exposures which I studied along the Canadian, and extends to within a few miles of the Rio Cimarron. According to Mr. Hill's section the Lower Cretaceous, consisting of the Trinity, Fredericksburg, and Washita, lies between the Red Beds and the Dakota. If Mr. Hill's section represents correctly the age of the formations in the Canadian valley, then the shales and possibly the Exeter sandstone, must be of Lower Cretaceous age. But the shales, as I have already shown, are probably the same as the dinosaur-bearing shales of the Purgatory. There is some probability, therefore, that the Morrison formation may be identical with some part of the Lower Cretaceous of the Texan region.

This suggestion and the argument supporting it would have force if Hill's generalized Texas section were applicable to the Canadian valley, and if sedimentation had been continuous from the Red Beds to the Dakota inclusive. Several years earlier Hill suggested the possible equivalence of the Atlantosaurus beds with the basal or Trinity group of the Comanche series.

[1] *Journal of Geology*, Vol. IX, pp. 343–52.

[2] *Journal of Geology*, Vol. X, pp. 36–58. [3] Pp. 56, 57.

The next step in the attempted correlation of the Morrison formation with the Comanche series was the announcement by Lee, at the Washington meeting of the Geological Society of America in 1902, that he had discovered *Gryphaea corrugata* Say, a characteristic Comanche fossil, in the Morrison shales on the Cimarron near Garrett, Oklahoma. Only brief abstracts of his paper, entitled "Age of the Atlantosaurus Beds," have been published.[1] His conclusion was that the non-marine Morrison formation is traceable laterally into marine shales of the Comanche series containing fossils that indicate a horizon within the Washita group, and that therefore the Morrison is of that age. Darton stated that he had observed similar relations on Butte Creek, southeastern Colorado, and he accepted Lee's interpretation. As Darton's current field-work covers the entire area from the Missouri River to the Wasatch Mountains, the immediate effect of the new correlation on the mapping and classification was far-reaching. In two published folios[2] of the *Geologic Atlas of the United States*, and in *Professional Paper No. 32*, "Geology and Underground Water Resources of the Central Great Plains,"[3] the Morrison formation is classified as Cretaceous and the chief reason assigned in every case is essentially that it "appears to be equivalent to a portion of the Comanche series in northwestern Oklahoma and southeastern Colorado."

Last June, through the courtesy of Mr. Darton, I was enabled to join Mr. Lee in the field and visit with him the exposures on the Purgatoire, the Cimarron, and the Canadian that he had previously studied. We were accompanied by Mr. C. W. Gilmore, of the U. S. National Museum, who is familiar with the dinosaurs of the Morrison. We also visited Mr. Darton's locality on Butte Creek, and later extended our observations as far south as Tucumcari, New Mexico.

[1] *Science*, New Series, Vol. XVII (1903), pp. 292, 293; Geological Society of America, *Bulletin*, Vol. XIV (1904), pp. 531, 532. *Science* gives a very brief account of the discussion that followed the reading of the paper but the reporter completely missed the point of Stanton's argument in opposition.

[2] "New Castle (Wyoming-South Dakota)," and "Edgemont (South Dakota-Nebraska)."

[3] See pp. 34, 96, 102, 141, and 164.

The general features of the whole region traversed have been well described by Lee[1] and the description need not be repeated except to say that it is a portion of the Great Plains region through which the principal streams have cut canyons several hundred feet deep, thus exposing good sections of the nearly horizontal strata. The Dakota sandstone always forms prominent cliffs near the top of the canyon walls and in some part of the course of each large stream the cutting extends as low as the Red Beds. The conditions are thus especially favorable for studying the strata immediately below the Dakota, as the Dakota itself, and many of the other hard beds are often continuously exposed for many miles, and furnish convenient, easily-recognized reference planes.

Purgatoire River.—Our first examinations were made on Purgatoire River at Higbee Plaza, about twenty miles south of La Junta, Colorado, where some marine invertebrate fossils, seen in the talus by Mr. Lee, gave us an important clue to the solution of our chief stratigraphic problem. At the top of the canyon wall is a cliff-forming gray and brown, mostly massive, cross-bedded sandstone, here fifty feet thick, but the upper part has been removed by modern erosion. Back from the river, where it passes under the Benton shales, its total thickness is not far from one hundred feet. This is unquestionably Dakota, as is attested by its stratigraphic position, its lithologic character and its flora, of which a few specimens, collected here and at other localities in the region, have been identified by Dr. Knowlton. Separated from this upper sandstone by about fifty feet of dark shales and thin-bedded sandstones, usually in large part covered by talus, is another lithologically similar coarse gray sandstone, varying in thickness from fifteen feet, or less, to sixty feet. This has also been referred to the Dakota by Lee, and probably by every geologist who has worked in southern Colorado, the intermediate more shaly portion being correlated with the "fire-clay band" of the earlier reports.

It was soon found that this intermediate shaly portion of the "Dakota" was the source of the fossils found in the talus below, and the fossils themselves were recognized as belonging to the

[1] *Journal of Geology*, Vol. IX, pp. 343–52; Vol. X, pp. 36–58; *Journal of Geography*, Vol. I, pp. 357–70; Vol. II, pp. 63–82.

Comanche fauna, although some of them belong to unnamed species and others are not well enough preserved to justify positive specific determination. Among those collected at this locality are:

Inoceramus comancheanus Cragin
Trigonia emoryi Conrad?
Cardium kansasense Meek
Cyprimeria sp.
Pholadomya sancti-sabae Roemer?

Farther up the Purgatoire, in the neighborhood of Chaquaqua Creek, where the underlying formations are better exposed, this fossiliferous horizon was easily recognized and fossils were collected from it in Browns Canyon, on the ridge east of Chaquaqua Creek, and in Iron Canyon. These localities added to the list of species *Protocardia texana* Conrad, *Leptosolen conradi* Meek and an unnamed species of *Tapes* (?) which also occurs in the Kiowa shales of Kansas. No specimens of *Gryphaea corrugata* were found on the Purgatoire, but the forms listed are elsewhere associates of that species and there is no doubt that the horizon is the equivalent of some part of the Washita group, and should be directly correlated with the Kiowa shales of southern Kansas. It must certainly be removed from the Dakota. The underlying sandstone, which has been called Lower Dakota, probably goes with the shales in the Comanche series, though the evidence on this point is not conclusive. Its variation in thickness and its absence from some sections would suggest a possible erosion interval after its deposition.

The variegated shales and the sandstones and limestones, of the Morrison with an average thickness of about 200 feet are partly exposed in the neighborhood of Higbee, but they may be better seen farther up the river especially near Chaquaqua Creek, about fifteen miles southwest of Higbee.

Here Mr. Lee had previously announced the occurrence of large dinosaurs, and Mr. Gilmore was able to recognize Brontosaurus and other dinosaur genera of the Morrison fauna. At the locality where the bones were seen in the greatest abundance, near the southeast corner of the Timpas quadrangle, the dinosaur horizon is about 200 feet below the marine Comanche fossils.

Beneath the Morrison formation, or possibly forming a member

of it, there are gypsiferous shales and gypsum varying greatly in thickness in different exposures, the maximum observed being 125 feet.

Immediately underlying the gypsum and forming the lowest exposures of the region are the Red Beds of which 200 or 300 feet are exposed over a considerable area, where the overlying formations have been removed from a broad, domelike uplift. They consist mainly of coarse, dark-red sandstones with some red and purplish shales and a few thin bands of white calcareous sandstone, which are conspicuous where they form the surface of low mesas. In the upper layers of the Red Beds, below the mouth of Chaquaqua Creek, Mr. Darton has collected a bone that has been identified as Belodon, indicating Triassic age.

The Purgatoire section may be summarized as follows:

1.	Benton shales, thickness probably not more than . . .	200 feet
2.	Dakota sandstone	100 "
3.	Dark shales and shaly sandstones with Comanche fauna .	50 to 100 "
4.	Coarse gray, cross-bedded sandstone	15 to 60 "
5.	Variegated shales, marls, sandstones and limestones of the Morrison formation, with Brontosaurus, etc.	200 "
6.	Gypsum and gypsiferous shales	70 to 125 "
7.	Red Beds with Belodon near top, exposed	200 to 300 "

With some variations in thickness and, in a few cases, the disappearance of one or more members, this section is essentially repeated throughout the area we examined in Oklahoma and New Mexico as far south as Tucumcari.

Two Buttes uplift.—On the way south from Lamar, Colorado, to the Cimarron in Oklahoma, the exposures were examined near Two Buttes, where Mr. Darton[1] had found the Comanche *Gryphaea corrugata*. Here the so-called Lower Dakota, beneath the fossiliferous Comanche shales and sandstones, appears to rest directly on the eroded surface of the Red Beds. Several additional Comanche species were collected, including *Pachydiscus brazoensis* (Shumard), and incidentally it was determined that the oyster bed reported by Darton as occurring in the Dakota of this region is probably beneath the true Dakota and in the Comanche.

[1] *Science*, New Series Vol. XXII, July 28, 1905, p. 120.

Rio Cimarron.—East of Garrett P. O. on the Cimarron in western Oklahoma, the Red Beds are exposed with a slight westerly dip which carries them below the surface near Garrett, and in that neighborhood the section extends up to the top of the Dakota.

The section generalized from observations covering a few square miles is as follows:

1.	Massive, coarse, cross-bedded gray and brown sandstone of the Dakota	150 feet
2.	Dark shales with layers of brown flaggy sandstone and bands of somewhat calcareous yellow sandstone with Comanche fauna	50 to 60 "
3.	Coarse, brown or gray cross-bedded sandstone with irregular bands of pebbles, apparently unconformable on the underlying stratum	4 to 15 "
4.	Variegated shales, gray sandstones and bands of siliceous limestone, referred to the Morrison, not well exposed. Thickness probably less than	100 "
5.	Red Beds.	

The Comanche horizon has yielded a varied fauna which is clearly the same as the Washita fauna that has long been known at Mesa Tucumcari, New Mexico, in northern Texas, and in the Kiowa shales of southern Kansas. The following species have been identified:

Gryphaea corrugata Say
Ostrea subovata Shumard
Ostrea quadriplicata Shumard
Plicatula incongrua Conrad
Inoceramus comancheanus Cragin
Gervilliopsis invaginata White
Trigonia emoryi Conrad
Protocardia multilineata Shumard
Pholadomya sancti-sabae Roemer?
Anchura kiowana Cragin?
Turritella seriatim-granulata Roemer
Hamites fremonti Marcou?
Pachydiscus brazoensis (Shumard).

This horizon was traced with practical continuity westward up the Cimarron to Folsom, New Mexico, a distance of about seventy-five miles across the strike. Its lithologic features show little variation and its thickness is never less than fifty feet nor more than one hundred

feet. Fossils gradually become less abundant in both species and individuals toward the west, until near Folsom only a small mactroid shell was found in considerable numbers. The most western point at which *Gryphaea corrugata* was collected is about thirty miles east of Folsom.

Along this line the coarse sandstone beneath the Comanche fossils is from fifteen to forty feet in thickness, and the variegated shales, sandstones, etc., of the Morrison increase to about 200 feet. Lithologically and stratigraphically this is identical with the Morrison beds seen on the Purgatoire where characteristic dinosaurs were collected. Fragmentary, undetermined, dinosaur remains were seen in it on the Cimarron near Exter, New Mexico.

Beneath the recognized Morrison some localities show forty to fifty feet of gypsum and gypsiferous shales resting on a massive white or pinkish sandstone which Mr. Lee has described as the Exter sandstone. It varies greatly in thickness, the maximum observed being eighty feet. The Exter is separated from the Red Beds by a striking angular unconformity, wherever the Red Beds are folded in local uplifts. The Red Beds show the usual character and at Tod's ranch, fifteen miles east of Folsom, they yielded fragmentary Triassic vertebrates.

From Folsom we traveled by rail to Tucumcari and from that place by wagon to Las Vegas.

Tucumcari region.—At Mesa Tucumcari the Dakota sandstone, eighty feet in thickness is underlain by sixty feet of fossiliferous Comanche shales and yellowish sandstones containing the same fauna as at Garrett, Oklahoma, with a few additions. The Morrison formation was not recognized but its place in the section is occupied by a talus slope with no exposures. The lower part of the section is composed of Red Beds of the ordinary character, overlain by friable, light-colored sandstone that is suggestive of the Exter.

At Mesa Redondo, a few miles south of Tucumcari, the space between the Comanche zone and the Red Beds is filled by 300 feet of heavy bedded gray and buff sandstones with intercalated thinner beds of red shales.

About ten miles northwest of Tucumcari station the section shows

[1] *Journal of Geology*, Vol. X (1902), p. 45.

considerable change. The Comanche fossiliferous zone, here only twenty-five feet thick, rests on 100 feet of coarse gray cross-bedded sandstone which in turn is underlain by 300 feet of variegated shales and sandstones very similar to those of the Morrison on the Cimarron and the Purgatoire. Fragmentary bones of large dinosaurs are common in these shales but none of these collected was sufficiently characteristic to be identified.

On the north side of Canadian River, fifteen miles northwest of Tucumcari, a similar section is exposed with only twenty feet of fossiliferous Comanche, and this is the last point in this direction at which Comanche fossils were found in place. Farther north and west in the neighborhood of Sanchez and on the upper course of the Rio Concha, the stratigraphic place of the Comanche is occupied by an inconspicuous shaly band in which no fossils were found. The other members of the section remain practically unchanged.

An occurrence of Unio previously discovered by Mr. Lee about 500 feet below the top of the Red Beds on Rio Concha is worthy of mention as indicating the post-Paleozoic age of that much of the Red Beds.

Canyon City.—At the end of the field season I visited the well-known Morrison locality in Garden Park, eight or nine miles north of Canyon City, Colorado. On Oil Creek, below Garden Park and about a mile south of the "Marsh quarry," which has yielded so many dinosaurs, the Dakota sandstone and associated strata are well exposed with a dip of 17° S. E. Guided by the experience gained on the Purgatoire and the Cimarron a brief search in the shaly strata beneath the upper cliff of Dakota sandstone was rewarded by the discovery of plentiful marine fossils that belong to the Comanche fauna. Those collected include *Pholadomya sancti-sabae* Roemer, a *Tapes* (?), a *Lingula* and a small mactroid shell, all of which occur in the Kiowa shales of Kansas. The cliffs at this point show the following section:

1.	Rather massive gray Dakota sandstone overlain by Benton shale	100 feet
2.	Dark gray shales alternating with thin-bedded sandstones. Marine Comanche fossils at 35 feet from top	85 "
3.	Massive gray sandstone with bands of fine conglomerate near top	35 "

4. Chocolate, reddish, and variegated shales and variable sandstones of the Morrison. Only upper part here exposed. Total thickness probably . . . . . 300 or 400 "

The general section of the region includes the entire Upper Cretaceous and a considerable thickness of Red Beds and Paleozoic.

Under the guidance of Mr. Edward Felch, who has had personal knowledge of all the vertebrate collecting that has been done in the neighborhood, I visited the various quarries that were worked by Marsh, Cope, and Hatcher, and determined that they are all on horizons below the Comanche fossiliferous bed and below the sandstone immediately underlying it. It is evident therefore that the Morrison formation is no more closely related to the Dakota near Canyon City than it is at other localities.

Extent of the Comanche Sea.—It has now been shown that the Comanche sea extended as far northwest as Canyon City, Colorado, and that its sediments overlie the Morrison in an area more than 100 miles wide. How much farther it extended in that direction is not known, as no special search for paleontologic evidence has yet been made, though the recent discovery by Prof. S. W. Williston[1] of Comanche species of fish teeth in the "upper part of the Atlantosaurus beds" near Lander, Wyoming, suggests the possibility of much greater extension.

This leads to the question whether the Fuson and Lakota formations, which have been differentiated from the Dakota in the Black Hills, should be identified respectively with the Comanche shaly beds and the underlying sandstone which hold the same stratigraphic positions in southern Colorado and New Mexico. Such an identification is plausible, and yet it seems to me that it is not warranted by the evidence now in hand. The Fuson formation is apparently non-marine, and, judging from the descriptions, its lithologic character is different from that of the Comanche shales and sandstones. It contains a flora which is comparable with that of the lower Potomac, and has nothing in common with the Dakota flora, which is of much later type. On the other hand, the Comanche[2] of Colorado

[1] *Journal of Geology*, Vol. XIII (1905), p. 347.

[2] The term Comanche throughout this paper is used as a general term of correlation—not as a formation name.

and New Mexico is the equivalent, in part at least, of the Kiowa and Mentor beds of Kansas which are very intimately connected with the Dakota, as Gould[1] has pointed out. This connection is shown by the flora as well as by apparent stratigraphic continuity. The Cheyenne sandstone which underlies the Kiowa in southern Kansas contains a flora not yet fully studied which is of the same type as the Dakota flora and includes some identical species.

In the neighborhood of Marquette, central Kansas, there are sandstone bands with Dakota species of plants intercalated in the marine beds with characteristic Comanche fauna. The paleobotanic evidence therefore tends to place the Fuson formation considerably lower in the general geologic column than the shaly Comanche beds beneath the Dakota in Colorado and Kansas.

Age of the Morrison.—The question whether the Morrison formation is Jurassic or Cretaceous is still to be answered, and if a satisfactory answer is ever received it will doubtless be from vertebrate paleontology, aided by careful stratigraphic methods. If the Morrison is Cretaceous, the proof that it is so will not be by tracing it directly into marine Cretaceous strata. It has been shown that the beds supposed to be thus connected with it overlie it for more than 100 miles across the strike. But these overlying beds are by no means the earliest Cretaceous, and there is still room for the Morrison within that system if the fauna requires such a reference. On the other hand, there is ample space for it in the Jurassic[2] not otherwise represented in the region by sediments, and before the final decision is made the character of the flora in the Fuson formation of the Black Hills and in the Kootanie of Montana should be given due weight, and these formations should be closely studied and searched for other evidence.

In this connection I may quote from the late Clarence King who, in speaking of paleontologists as "these scientific autocrats," says:[3]

[1] *American Journal of Science*, 4th series, Vol. V (1898), pp. 169–75; *American Geologist*, Vol. XXV, pp. 10–40.

[2] The marine Jurassic Sundance formation, characterized by *Cardioceras cordiforme* M & H, etc., on which the Morrison rests in the northern area, does not represent the latest Jurassic according to European standards

[3] *Report Chief of Engineers*, U. S. Army, 1875, p. 919.

It is the misfortune of geology to be more or less dependent on this branch of specialists. Without their specific determinations the geological maps, even, cannot receive their ultimate color designations, nor can reports, which, like ours, involve a wide range of stratigraphy, be safely written.

It may seem autocratic, but in these days the paleontologist insists, not only that his specific determinations must be used, but that he must be consulted as to the interpretation that is placed upon his lists, and especially he insists that the geologist must know what horizon yielded the fossils under discussion before he uses them in stratigraphy and correlation.

TERTIARY FORMATIONS OF OLTENIA WITH REGARD TO SALT, PETROLEUM, AND MINERAL SPRINGS

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INTRODUCTION

In Oltenia, the western part of Roumania, there are three geological regions:

1. The mountains to the north, a part of the Carpathian chain,

formed by eruptive rocks, metamorphosed schists, and sedimentary deposits, the uppermost being the Lower Cretaceous, with a Flysch basin in the Olt valley, the basin Brezoi-Titesti.

2. The high plateau of Mehedinti to the west, constituted by the same formation, but with small tertiary Neogene fjords and basins.

3. The Tertiary foothills, with a characteristic depression near the mountains, the so-called Subcarpathian depression.

The researches on Tertiary formations in Roumania have usually touched only casually the region west of the Olt River, and still less the Subcarpathian region between the Olt and Jiu Rivers. The valuable work by Fuchs, Foetterle, Tournouëri, Porumbaru, Fontannes, Toula, etc., refers in general only to the highest layers, Pontic and Levantine, of Oltenia; and even the extensive study by Sabba Stefanescu, on the whole Roumanian Tertiary, gives us very few facts about the northern part of this region, which appears as uniform and without interest. In this respect, however, we must remember the scattered observations by Gr. Stefanescu, and the study by K. Redlich, exhaustive on some points, which permit us to see how interesting a detailed study of this region might be.

In this paper I propose to present the stratigraphical results of my researches, extending over five years in the complicated petroleum and salt region, and over several years more in the mountains of Oltenia. The paleontological determinations, which throw light on and confirm my field observations, were made by Professors A. Koch, N. Andrussow, and W. Lascareff, to whom I here present my heartiest acknowledgments.

THE NORTH ZONE OF THE TERTIARY OF OLTENIA
BREZOI-TITESTI BASIN

The earliest studies, especially by Grégoire[1] and Sabba Stefanescu,[2] have presented the region west of Olt and south of the boundary of the crystalline formations, as constituted in its whole extent, right up to the Danube, by tertiary deposits only. Later Dr. K.

[1] Grégoire Stefanescu, *Annuaire du Bureau géologique*, année 1882–83; *Carte géologique de la Roumanie; Cours de géologie*, 1891, etc.

[2] Sabba Stefanescu, *Etude sur les terrains tertiaires de Roumanie*, 1897; "Mém. sur la géol. du Jud. Arges," *Ann. d. Bur. Géol. Roum.*, 1882–83; several notes in the *Bull. de la Soc. géol. de France*, 1894, etc.

Redlich[1] has shown that the marls, sandstones, and conglomerates of the Brezoi Basin, which on Gr. Stefanescu's map were figured with the color for Eocene with a point of interrogation, belong to the Senonian, the horizon with *Inoceramus Cripsii;* he suggested that similar formations lower than Eocene strata, in the neighboring Titesti Basin, might belong also to this horizon.

1. It may be that the conglomerates above the Brezoi breccia,[2] mica sandstones and marls, which form the mountains to the northwest of the Cozia Monastery and Sturii Olanestilor up to the Piatra Stogului, can be ascribed to the upper Cretaceous (Cenomanian upward).[3] I can adduce as evidence the topographic continuity of these deposits with the Senonian strata from the Brezoi Basin through the Stan valley, and the identical facies and composition of the rocks from these two places. These are: coarse conglomerates, shingle, and sandstones with crystalline rock elements at the contact with the crystalline foundation; finer sandstones and marls farther off from this contact.

Stratigraphical and tectonical considerations speak even more for the synchronism of these deposits (see below). L. Mrazec, in a communication to the Society of Science (Bucharest, February, 1904), expresses the same hypothesis for the Brezoi breccia from the Arges valley (Capatineni) which underlie the Eocene strata (described by Sabba Stefanescu); K. Redlich makes also the same suggestion for representatives of the same breccia and conglomerates in the west of Salatrucu. The strata about which I am writing are lower than the horizon to which Redlich and Mrazec refer.

I may add that many years ago I found at Vf. Candoaia on the mica schists transgressive siliceous mica sandstone like that from

[1] K. Redlich, "Geologische Studien um Gebiete des Olt- und Oltetzthales in Rumänien," *Jahrbuch der k. k. geolog. Reichsanstalt*, 1899. Three notes in *Verhandlungen*, etc.

[2] A (Liassic ?) breccia which forms the foundation of the Brezoi Basin and the limestone, also the higher deposits on the Narutu, Sida, Foarfeca, Folia Mountains and the foundation of the sedimentary formations at the skirt of the mountains. G. M. Murgoci, "Calcare si fenomene de erosiune in Carpati merid." *Bull. Soc. Sciences Bucharest*, 1898.

[3] Suggested already by L. Mrazec and myself in "Muntii Lotrului," *Bull. Soc. Ing. mine*, 1898.

the Vasilatu valley (west of Brezoi), which has here and there traces of undeterminable fossils, but where *Inoceramus* can be distinguished.

2. On the other hand, I do not think that the whole deposits from the Brezoi Basin are Senonian, but that the upper strata belong to the Eocene, corresponding to the Eocene strata from the opposite Titesti Basin. Dr. Redlich tells us that in the strata with *Orbitoides* (upon the sandstones and marls with *Inoceramus*), he has found a section similar to one of *Nummulites;* still more important evidence is revealed to us by the stratigraphy and facies of the deposits (Figs. 1 and 4).

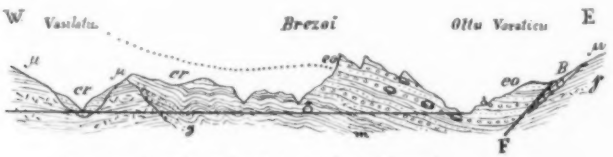


FIG. 1.—Profile of the Lotru valley at Brezoi; 1 : 100,000.

μ = Mica schist with p = pegmatite veins; B = Brezoi breccia; cr = Upper Cretaceous; g = sandstone and grit; m = marls and sandstone with *Inoceramus Cripsii;* co = coarse conglomerates with *Hippurites* limestone blocks; F = fault.

Omitting the consideration of the Brezoi breccia, we find that the coarse conglomerates, shingle, and sandstones with an intercalation, in the lower horizon, of a thick bank of marls and fine silicious sandstones, bend themselves into small undulations, with an anticline more pronounced on the side of the Calimanesti valley. Between Brezoi and Valea lui Stan I can confirm a small syncline with many folds in the marls. The whole formation is inclined toward the southeast (angle variable from 30°–60°), and it lies in obvious unconformability on the mica-schists and Brezoi breccia, which form klippes at the bottom of these deposits. A fault along the right bank of the Lotru has been confirmed by Dr. Redlich and myself at the same time.[1]

The marls, contrary to the interpretation of K. Redlich, constitute a horizon intermediate between the conglomerates and sandstones from the Vasilatu valley, which are rich in Senonian fossils, and the coarse conglomerates in the east of Brezoi, rich in huge blocks of limestone, with Senonian fauna.

[1] *Loc. cit.* (footnote 1, p. 672).

From the marly-sandy layers of the Stupinita ravine Dr. Redlich cited:

Inoceramus Cripsii.
Orbitoides Faujasi Brown.
Orbitoides secans Leym.
Astrocoenia sp.
Serpula filiformia Sow.
Pecten inversum Nils.
Actinacis Haueri Rs.
Avellana sp.
Baculites anceps Lam.
Anisoceras cf. subconopresum Forb.

He found in the blocks of a white, grayish, or reddish limestone, with red veins, a numerous fauna, among which are:

Hippurites Lapeirousei Goldf.
Hippurites colliciatus Woodw. var. *romanica.*
Orbitoides gensacica Leym.
Orbitoides secans Leym.
Lithothamnium cf. turonicum Roth.
Terebratula carnea Sow.
Terebratula biplicata Brocc.
Lima tecta D'Orb.
Lima divaricata Duj.
Lima inversum Nils.
Gryphaea vesicularis Lamk.
Exogyra sp.
etc., etc., etc.
And two new species:
Terebratella Mrazeki.
Waldheimia Pascuensis.

Dr. Redlich, considering that the conglomerates which contain these certainly Senonian limestone blocks underlie the above-mentioned Senonian marls and sandstones, expresses his opinion that these blocks are destruction products of a bank of *Hippurites* limestone which was formed within the conglomerates. But the conglomerate layers with these interesting blocks overlie the marls and sandstones with *Inoceramus Cripsii*,[1] and I think I am making no mistake in saying that they are an Eocene formation.

Besides the *Nummulites* indicated by Redlich in the lower strata, with *Orbitoides*, of this complex, I adduce the identity in constitution and the continuity with the strata from the Titesti Basin, where in layers immediately on those banks of conglomerates Sabba Stefanescu and K. Redlich have collected abundant Middle Eocene fossils.

Such blocks of *Hippurites* and *Coral* limestone are very frequent, not only in the Brezoi-Titesti Basin, but also in the Eocene conglomerates, which form a zone from Arifu (Arges valley) at Salatrucu, Calimanesti, up to Cheia (Valcea). In the coarse conglomerates Sabba and Gr. Stefanescu have found also numerous Middle Eocene fossils. At Calimanesti-Salatrucu the conglomerates are overlain by

[1] *Loc. cit.* (footnotes 2 and 3, p. 672).

marls and sandstones similar as to facies and fauna to the upper marly layers from the Titesti Basin; Redlich indicates, further, on his sketch an anticline between the Titesti Basin and Salatrucu Dangesti; this suggests to me that the marls from Titesti may be the same horizon as those from Salatrucu-Calimanesti, and then the correspondence between the conglomerates from Brezoi Basin and the similar ones from Arifu-Cheia would be even more obvious and unassailable. In this case the Flysch of Brezoi-Titesti presents the same character of facies which is described for the whole Carpathian Flysch; Cenomanian = coarse conglomerates; Senonian = marls and sandstones; Middle Eocene = very coarse conglomerates with huge *Hippurites* limestone blocks, etc.[1]

From these speculations it follows that the lower Flysch has made an anticline above the Narutu and Cozia Massif, which has been in parts sunk along the Lotru valley, eroded up the ridge, but traces of it were still left in the Valea lui Stan, the small basin at the Turnu monastery and between Baesti and Dangesti.

TERTIARY OF THE SUBCARPATHIAN REGION

In the foothills of Oltenia the Tertiary is represented in the whole of its development from the Eocene to the Pleistocene beds. Its general character here is a continuity of deposits, chiefly in the Olt region, from the Cretaceous up to the Levantine; but only a critical and detailed study of the strata, now violently dislocated, can reveal to us the early partially conformable succession. In the western part there may be observed the uninterrupted succession of deposits only from the Mediterranean Sea to the Levantine lake, and also a persistence of facies along the skirt of the mountains, the persistent strand of the sea.

A. THE FLYSCH OF THE UPPER PALEOGENE

On the geological map by Grégoire Stefanescu the Eocene formations are drawn correctly in their extension toward the south; their edge passes near Suici (Topologu V.), enters into the Oltu valley at Daesti, and runs with small undulations toward the west, reaching

[1] See about this question the masterly researches by V. Uhlig. A clear résumé is: "Ueber die Klippen der Karpathen," *Comptes Rendus, IX^e Congrès Géol.*, 1903 Vienne.

Mirlesti-Petreni, where the deposits overlie the Jurassic massif of Bistrita. Between Cozia and the south boundary of the Paleogene formations I can distinguish three horizons.

1. *Lower*, lying to the north of the line Dangesti-Calimanesti-Olanesti-bai-Cheia, a zone of sandstone with hieroglyphs and Strzalca structure, conglomerates, and a few marls with fucoids. In their highest beds the silicious conglomerates and grits contain, as mentioned above, huge blocks of *Hippurites* limestone, which are to be found in every valley from Arifu up to Cheia. *Orbitoides* and *Nummulites* (*Nummulites Lucassana*, *N. perforata*, etc.) have been found here, proving it to be the Middle Eocene. Last summer Gr. Stefanescu found at Calimanesti, in these conglomerates, *Cerithium giganteum* Lam., which was found also by Sabba Stefanescu at the prolongation of these beds at Salatrucu in the Topologa valley.

2. *Middle.*—There now comes a zone of marls with a few sandstone and sand beds, which give their character to a region of meadows between Jiblea and Cheia (the meadows of Jiblea, Calimanesti, Muereasca, Olanesti, Tisa, and Cheia).

In repeated sandstone beds in the Puturosita ravine (Calimanesti) in the Purdoi bank and the Olanesti village, I have found[1] the following fossils, which are identified by Professor A. Koch of Budapest:

Nummulites Bucheri De la Harpe
Nummulites Tournouëri De la Harpe
Nummulites Budensis Hant.
Nummulites aff. Madariszi Hant.
Orbitoides papiracea Boubée
Orbitoides aspera Güm.
Orbitoides applanata Güm.
Operculina cf. ammonea Leym.
Alveolina cf. Bosci D'Orb.
Nodosaria latijugata Gumb.
Nodosaria baccillum Defr.
Heterostegina sp.
Cidaris cf. subularis D'Arch.
Macandroseris (?)
Bourgueticrinus elipticus D'Orb.
Bourgueticrinus Thorenti D'Arch.
Bryozoa, *Cidaris*, *Cerithium*
Cardium, *Cardita*, *Ostrea*, etc.

From this fauna Professor A. Koch concludes that we have here to do with the Upper Eocene, but the presence of *Operculina ammonea* gives us a transition to the Middle Eocene, and that of *Nodosaria latijugata* and other fossils a transition to the Lower Oligocene. Sabba Stefanescu, who studied this horizon in the Topologu and Argesu valleys is similarly of opinion that this marly facies began to

[1] I have described these localities in *Gisements du Succin de Roumanie. Assoc. p. In. si Resp. Sciintelor*, 1903, *Mém. Congrès* Iasi.

be deposited at the end of the Middle Eocene and continued until the Oligocene. In this horizon there occurs the fossil resin of Olanesti (malul Purdoi) and Cheia.[1]

3. *Upper.*—We find in the southern region of Muereasca another zone of sand and shingle and limestone blocks with, at rare intervals, bands of conglomerates and sandstones. At Muereasca de jos I have found Nummulites and Orbitoides, which are indications of Oligocene, but characteristic of no particular horizon; probably we have here beds also of the Lower Oligocene. All these formations have in the Olt valley a direction southeast by east to northeast by east,

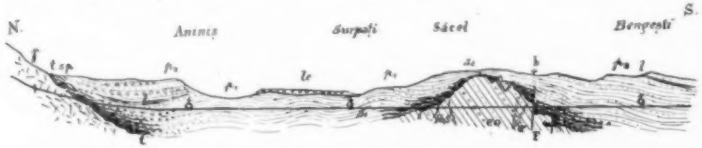


FIG. 2.—Profile of the Blahnita valley.

g=granite; *eo*=Eocene conglomerate and grit with (H_2S) sulphur and (σ) salt springs; *t*=Tortonian conglomerate and *Lithothamnium* limestone; s_2=Lower Sarmatian; s_3=Middle Sarmatian; p_1=Lower Pontic with *Valenciennesia;* p_2=Upper Pontic with *Vivipara bifarcinata;* *l*=Lignite seams; *le*=Levantine shingle.

and dip south-southeast at a quite variable angle of about 40°. In the west of Cheia we find them running from east to west, and in the east of Dangesti also K. Redlich and Sabba Stefanescu report an east-to-west direction for these beds. Obviously the Paleogenic Flysch must make an interesting horizontal inflection in the Olt region. Insignificant undulations, but not folds, are also to be seen here and there (at Olanesti below the spa, etc.).

We meet, further, with the Paleogenic formations in close relation with the mountains only in the high plateau of Mehedinti, where they form a narrow zone westward from Baia de Arama up to Batta.

B. THE PALEOGENIC KLIPPES OF SACEL AND SLATIOARA

When we leave the Olt region, we find the Eocene appearing as a small but interesting klippe in the Blahnita valley at Sacel (Gorj.). It includes conglomerates, grits, and sandstones identical with those from Calimanesti (Valcea), inclined at an angle of 50°–60° toward the south-southeast, and constituting the bottom and walls of the valley, about 600^m (Fig. 2). This cliff has been the subject of much discussion between Gr. and Sabba Stefanescu.

[1] G. M. Murgoci, *Gisements du Succin de Roumanie. Assoc. p. In-Sciintelor,* 1903.

The former geologist, although he did not find any fossils, considered it, judging from the facies and occurrence, to be Eocene, and figured it as such on his map; the latter at first described it as Sarmatian,[1] but after the publication of Gr. Stefanescu's reply[2] changed his views and assumed the conglomerates to be Tortonian like those from the skirt of the mountains.[3] Some three years ago, however, I was fortunate enough to find here in the grit stratum below the Villa Speranta many imperfectly preserved *Nummulites* and *Orbitoides* (*Orbitoides papiracea* Boub.), and last summer I collected in the northern beds a large number of *Nummulites*, *Orbitoides*, *Corals*, *Operculina* (*ammonea*), *Cidaris*, etc., which would indicate the same horizon as at Olanesti-Calimanesti, the Middle Eocene in transition to the upper Eocene. But we must be wary, because these Eocene conglomerates are covered by transgressive beds of Tortonian and Sarmatian conglomerates (see below).

Gr. Stefanescu figures on his map another still larger Eocene klippe at Slatioara, about which Sabba Stefanescu says nothing; on the several occasions of my visits to this point I have not been successful in finding fossils. However, I am inclined to believe that only the shingle beds and loose conglomerates which constitute the Magurica and both walls of the Cerna valley are Oligocene. Like the Sacel Cliff, these beds retain the same direction and inclination, and have the same constitution—crystalline schists, granite, white and reddish limestone, conglomerates, etc.—as the corresponding beds of the Olanesti-Muereasca. The Slatioara klippe is covered transgressively by the more recent strata of the salt formation and Pontic. (Fig. 3.)

Mineral springs and natural gas.—The Middle Eocene conglomerates are characterized by many mineral springs, salt and sulphur springs occurring in the bottom of almost every valley, and the foot of the klippes, the chief being Jiblea, Calimanesti (spa), Muereasca de sus, Olanesti (spa), Cheia, Dobriceni; Slatioara, Sacel (spa).

Another line of springs is farther to the north at the contact of the

[1] "L'âge géologique des conglomérats de Muntenia," *Bullet. d. l. Soc. géol. de France*, Vol. XXII, p. 229.

[2] "L'âge géologique des conglomérats de Sacel," *ibid.*, p. 502.

[3] Sabba Stefanescu, *Etudes des terrains tertiaires de Roumanie* (1897), p. 112.

Cretaceous conglomerates with the crystalline rocks: Bivolari (hot springs), Puturoasa, Posta, Lacul Doamnei, etc.

Between these two series of springs there is the widely known alkaline spring of Caciulata, on the bank of the Olt River. Most of these springs are very rich in emanations of gaseous hydrocarbons, there being up to 97 per cent.[1] methane, but only 2 per cent. H_2S. While the origin of H_2S can readily be explained from the occurrence of partly altered pyrites in the mica schists,[2] which are among the constituents of the conglomerates, the large percentage of methane is not easy to understand; though probably the springs are in relation

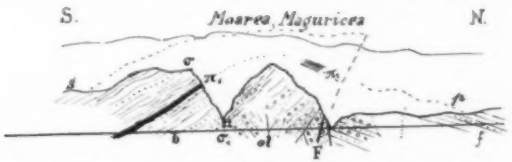


FIG. 3.—Profile of the Cerna valley at Slatioara.

ol=coarse Oligocene conglomerate and shingle; σ^1=lower salt formation (Burdigalian); π_1=*Palla* (Dacite tuff); σ=upper salt formation; *s*=Sarmatian; *p*=Mœotic and Lower Pontic marl and sandstone with (*f*) *Helix* and *Lymnea*; *F*=fault.

with petroleum-containing layers. The salt springs (Calimanesti, Slatiora, Sacel, etc.) indicate a salt deposit in connection with the petroleum, such as is usual in all petroleum regions.

C. NEOGENE FORMATIONS, MIOCENE SERIES

The lowest stage of the Neogene, the Burdigalian, was studied in the south Carpathians by Stur, Hoffmann, Koch, etc., at Petrosani, in Transylvania; by Gr. Stefanescu, Draghiceanu, Fuchs, and Sabba Stefanescu, at Bahna, Balta, Fantanele, etc., in Jud Mehedinti, where the *I* Mediterranean Sea deposits form smaller or larger basins in the crystalline zone. I have mentioned these deposits as occurring at the south of the Carpathians at Gura Vai on the Oltu River.[3]

[1] Analysis by Gr. Pfeifer, "On the Olanesti Springs" (in manuscript); about Caciulata spring he has published his results in *Bul. Soc. Sciinte Bucharest*, Vol. III (1904).

[2] A sulphur spring occurs in the crystalline region of Puturoasa sub Pleasa in the bottom of the Romani valley; the mineral water comes from the red and brown altered, pyrites-bearing mica schists. Dr. Redlich cites a similar spring from the conglomerates of Brezoi (*loc. cit.*).

[3] Communication to the Society of Science (Bucharest, May 6, 1902); description in *Gisements du Succin de Roumanie*, 1903, *loc. cit.*

They consist of sands and loose sandstones, with large crystals of gypsum, and of a few sandy marls and conglomcrates, and they lie conformably on the similar formations of the Oligocene. In a valley in the west part of the village of Gura Vai, I have found in these beds *Cerithium plicatum* Brug (?) var. *papillatum* Sabba), *Cerithium margaritaceum* Brocc., etc.

I may add, as a result of my last summer's study, that the Burdigalian layers of Fântânele, Ponoare, and Balta form a narrow continuous zone, a Mediterranean fjord, in the high plateau of Mehedinti, The Bahna basin is of course the continuation of this zone, though separated by a strong later erosion. The layers of Ponoare, with some thin lignite seams, very often show a strong efflorescence of salt, etc., like those from Gura Vai.

Bearing in mind the presence of *Cerithium plicatum* in the other basins, and of bituminous coal at Gura Vai, just as in Bahna, and the Balta, etc., Basin, and more especially noticing some nuances of *Cerithium margaritaceum* (to use Professor Laskaroff's expression), we have reason to consider these beds to belong to the *I* Mediterranean layers. They reach westward to Cheia, and on the east they cross the Olt and extend to Daesti, etc. Some salt efflorescences may be mentioned as occurring in the sand marls at the Bogdanesti bridge, etc.

D. SALT FORMATION

There follows on the *Cerithium plicatum* strata in the Olt valley and westward a complex of marly, sandy formation which often lies unconformably on the Oligocene, and which is characterized throughout its whole extent by a well-marked saline efflorescence, by salt springs, and by a dacite tuff, the *palla* of the Hungarian geologists. In the true salt formation I found no fossils, but some found in higher strata indicate either Tortonian or the lowest Sarmatian strata, so that the salt formation would be intercalated between the Burdigalian and the Sarmatian. It has two petrographical features of great importance—the repeated palla beds, and the great salt massif of Ocnele Mari. In his sketch Sabba Stefanescu figures the salt as Helvetian (Subcarpathian salt formation), but without further description. However, on considering facies, tectonic, presence of palla, and indications given by the salt, I came to the conclusion that

the whole formation was Schlier, and as such it was figured in the sketch of the salt formation by Mrazec and Teisseyre.

Where the salt formations rest on the strata with *Cerithium plicatum* we cannot distinguish the exact limit of each, because, as mentioned above, they are in continuity; from Cacova up to Petreni the Schlier lies unconformably on the Oligocene, and at Bistrita on the Jura limestone. The prolongation southward is easier to define, because there the Sarmatian layers are rich in fossils.

In the Subcarpathian salt formation of Oltenia we can distinguish two horizons very well characterized by two facies, which, contrary to received opinion,[1] are very similar to, if not identical with, those of the bend of the Carpathians, and especially of the Slanic basin and Trotusu valley.

1. *The lower horizon of the salt formation.*—The lower horizon is of a sandy facies, with small intercalations of conglomerates, and bluish or reddish sandy marls corresponding with the reddish facies of the salt formation in the east. The colored bands of those deposits can be seen from afar in the walls of the valley and the river beds, viz., at Gura-Vai-Daesti; along the Olt River between Bujoreni, north and south Fedelesoaia-Cetatuia, at Bujoreni, in the Trantu valley, Runcu, etc.; then at Govora Spa, Tomsani, Maldaresti, etc. Two small bands of palla of a fine grain, and with scales of hexagonal biotite, occur on the banks of the Olt, under the salt wells from Olteni. Between Bujoreni and Vladesti the salt formation is covered by the marly facies of the Sarmatic layers, and can then be seen only in the beds of the valleys. At Runcu, at the head of the Trantu valley, this facies appears again very well marked, and with a large and characteristic palla bed. Here may be seen a variety of palla with very many foreign sedimentary elements, of the size of a hazelnut. The water-worn constituents are of quartzites, sandstones, limestones, schists, etc. In the Olt valley the banks fall south-southeast, almost 30°, and in the west we find this formation much

[1] Messrs. Mrazec and Teisseyre, in their valuable research on salt formations in Roumania (*Moniteur du Pêtrole roumain*, 1902), dwelt just a little on this basin. It must not be forgotten that at that time neither the existence of the two horizons nor the extent of the salt formations was known. Palla also was not identified, but confused, as was the case with all earlier geologists, with the silicious calcareous marl or sandstone.

FIG. 4.—Profile of the Olt valley in the Subcarpathian region.

L. = 1 : 200,000; H. = 1 : 75,000; μ = mica schists; (γ) = pegmatites and granite and Cozia gneiss; *B* = Brezoi-breccia; cr_2 = Cenomanian conglomerates; cr_3 = Senonian marls and sandstone with *Inoceramus Cripsii*; eo_2 = Lower and Middle Eocene marl with fucoids and strzalca structure and coarse conglomerates with *Hippurites* and *Coral* limestone; eo_3 = Upper Eocene marls and sandstone; *ol* = Oligocene sandstone and conglomerate; *b* = lower salt formation. (Burdigalian) sandstone, sand, and marl, with *Cerithium plicatum*; π_1 = palla; π_2 = levigated palla; *σ* = upper salt formation Tortonian marl and sand; s_1 = Lower Sarmatian with *Ervilia podolica*; s_2 = Middle Sarmatian sandstone and conglomerate; *Sm* = Upper Sarmatian and Meotic conglomerate and limestone with *Dosinia exoleta*; *p* = Upper Pontic with lignite seams and *Viviparа bifarcinata*; *a* = Alluvium; *F* = fault.

dislocated and folded, following the core of the two chief anticlines. (Fig. 4.)

Some faults at Bujoreni-Fedelesoaia bring the upper formations (Sarmatian) in contact with the banded salt formation. In the southern region, at Ocnele Mari-Govora, this horizon is constituted almost exclusively of sand with shingle and small banks of sandstone or conglomerates; the deposits present here the character of a delta with violently rushing arms.

A very interesting point of this horizon is at Casa Arendasului (Govora), where we find an intercalation of marls and more or less dissolved gypsum beds between the uniform sand and shingle strata. This horizon occurs in the middle of an eroded anticline, and has often a lenticular form; it is limited here and there by faults. Northward from Govora Spa it touches and passes into the banded facies; at Aninoasa, south of Slatiora, it reappears with the delta or torrential facies.

In the ravines of Ocnele Mari quantities of fossil débris may be seen, and I have found very many small *Nummulites* and *Orbitoides*, all somewhat eroded.

Nummulites was collected also from a conglomerate bank north of Govora Spa, also in secondary beds. In the ravines below Titireciu I found in the same torrential strata fossil débris in quantity, where *Cerithium plicatum* Brug., *Cerithium lignitarum* Eichw., and *Corbula* sp., could be determined.

These fossils show us that the lower horizon of the salt formation, with its sandy conglomerate facies, is the continuation of the strata of Gura Vai, and accordingly is to be classified under the *I* Mediterranean Sea deposits. To the west of Govora Spa, at Folesti-Tomsani and Maldaresti, the layer with the banded facies is very thick, and though fossils are not found, it is not impossible that the lowest beds should belong to the Oligocene; the same arrangement is to be observed at Barbatesti, where the beds seem to be a continuation of the Oligocene strata like those from Gura Vai (Olt). In the Slanic and Trotusu Basins, and also in the north Carpathians (Galicia, etc.), this horizon of the Subcarpathian Miocene salt formation occurs, according to the description of Mrazec and Teisseyre,[1] Zuber,[2] etc., similarly to the Oltenian one.

The salt formations of the Olt region, and indeed the whole Subcarpathian salt formation, have accordingly come down in the world as far as and including the Burdigalian.

The occurrence of eroded *Nummulites* near Ocnele Mari-Govora is evidence that in *I* Mediterranean times a redeposition of Paleogenic material took place; this view is supported also by the topographical and stratigraphical relations of the two formations in contact. The conclusion from these facts is, as proved for other localities in the Carpathians, that *at the end of the Oligocene, and beginning of the Burdigalian age there was an important dislocation in this region, more pronounced in the west at the contact with the skirt of the Carpathians.*

a) Petroleum and salt.—This formation is important, because in it we find: petroleum at Gavora Spa, and Ferbea; natural gas at Ocnele Mari, Teiusu, Gatejesti,[3] Pausesti, Barlog, Valeni, etc.; mineral wells, containing iodine, etc., at Gavora, Bunesti, etc.; and salt wells at Olteni, Govora Spa, Pausesti (de Otasau), Slatiora, etc.; and many localities with salt efflorescences. The petroleum

[1] *Loc. cit.;* Ueber die oligocen. Klippe bei Bacau," *Verhandlungen d. geol. Reichsanstalt*, 1902. W. Teisseyre, "Die Geologie der Bacauer Karpathen," *Jahrbuch der Reichsanstalt*, 1897.

[2] Zuber, *Geologie der Erdölablagerungen in den galizischen Karpathen*, 1899.

[3] Some of these localities are mentioned by Gr. Stefanescu, *Annuaire du Bureau géol. de Roum.*, I, p., 73 etc. (1882–83); and V. Tacit, "Regiunea petrolifera din Valcea," *Moniteur du Pétrol. Roum.*, 1901.

and natural gas occur here along an anticline dislocated by a fault which extends from Govora Spa to Otasani.

That fault explains why at Govora Spa we have two wells, at a distance of a few meters only, with totally different mineral waters; one well is bored in the lower salt formation, the other in the higher.

b) *The Slatioara anticline.*—We have stated that the shingle and sand with conglomerates was considered by Gr. Stefanescu to be Eocene, but from the tectonic and the facies it seems to me that the western part, at least, at Magurícea in the Cerna valley must be Oligocene. (Fig. 3.) The adjoining Sections (Figs. 5 and 6) summarize the

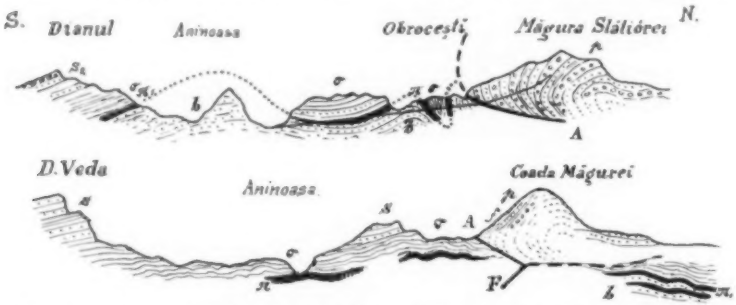


FIG. 5 and 6.—Sections through the Magura Slatioarei. The letters represent the same formations as in Fig. 4.
A = thrust plane; *F* = fault; *f* = Mœotic (or Pontic) layers with *Helix*.

stratigraphical and tectonical facts. At Magurícea, in the Moarea valley (Fig. 3), the lower banded facies of the conglomerates of the salt formation rests unconformably on the Oligocene shingle. While some sulphur springs with hydrocarbons originate in the Oligocene shingle beds, other ones, as well as the salt springs, come from the salt formations, which in the higher horizon contain an intercalation of palla. The continuation of palla on the north side of Magurícea and Coada Magurei indicates an old anticline. While at Magurícea the banded salt formation rests undisturbed above the Oligocene beds, in the east we find the whole salt formation folded and thrust southward, and a very obvious overlapping of the Pontic strata above the salt formation. This is well seen at Coada Magurei and eastward (Figs. 5 and 6): there, over the folded marls with intercalations of palla covered by Sarmatian strata, come the Mœotic (or Pontic?)

conglomerates, sands and sandy marls, with *Helicidae*, inclined at 70°, and resting apparently with their end above the Miocene basis. Between Cerna valley and Coada Magurei there are very many ravines with beautifully exposed sections; in one the folding of the salt formation may be shown; in another, the overlapping of the Pontic folded strata over the salt formation. The Pontic strata are evidence here of a redeposition of the Oligocene, perhaps also of the Burdigalian beds (see general considerations).

2. *The upper horizon of the salt formation.*—The upper horizon of the salt formation is formed by deep banks of green or gray marls and clays with *Globigerina* (Mrazec and Teisseyre), and repeated beds of palla, sand, and sandstone. The sand is better represented,

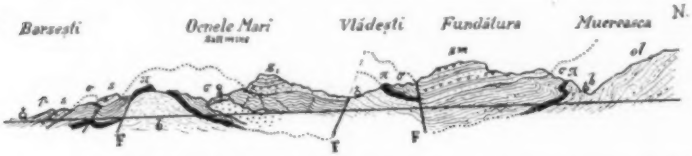


FIG. 7.—Section through the Ocnele Mari salt basin. The letters represent the same formations as in Fig. 4.

but the conglomerates all but wanting. It would correspond to the gray marly facies of the east and north salt formation. The depth of this formation is variable: At Ocnele Mari (Fig. 7), where a salt massif is intercalated, it is of considerable thickness; at Slatioara, however, it is not 50^{m} thick. This horizon is very well defined; as substratum we find often large quantities of palla, which here has, very rarely, an eruptive or crystalline facies. This palla is very fine, like pumice or chalk; in one place it is compact with conchoidal fracture, without stratification, but with fluidal zones, and of a white, yellow, or bluish color, and it is very similar to *Trass;* in another it is porous, friable, sandy, like tripoli, and not wanting in diatomaceous débris. All transitions can be found between true vulcanic dacite tuff or ash, and marl or sandstone, according to the percentage of foreign sedimentary elements which it may contain. That it was transported and deposited by sea waves is obvious. The calcareous variety is very rare (at Vladesti, Valcea); the sandy is the most developed. In its macroscopical and microscopical characters it is

similar to the Slanic and the Transylvanian palla. About the origin of this palla see below under "Pontic tuff."

In Oltenia palla is a bed characteristic of the lower limit of this facies; I have followed it eastward over the Olt valley, and westward up to Slatioara.

As hanging, the salt formation has thick banks of marls and sandy clays very finely banded, the gray or bluish *Tegel* of Austria-Hungary; the bands, which are sometimes as thin as a sheet of paper, arise owing to difference in composition, as well as difference of subsequent alteration. This complex, the upper strata of which have intercalations of sandstone or sand beds, belong partly to the lower Sarmatian (Buglowian) with *Syndosmya apelina* and *Ervilia pusilla.*

FIG. 8.—Profile of the Govora valley. The letters represent the same formations as in Fig. 4.

g=gypsum bed; F=sand and grit with *Cerithium plicatum; f*=sand with *Ervilia pusilla; L*=lignite layers.

Near to the coast and to the old cliff there took place in these marls some intercalations of sandstone and conglomerates with vegetable detritus, and dark porous limestone or gray-bluish calcareous marls, smelling strongly of petroleum. *We may consider all these latter formations as deposits from the II Mediterranean Sea.*

I have found no fossils in this horizon, but the deposits here are similar, as regards stratigraphy and facies, to the Tortonian deposits from the west, which are, according to their fossils, classified as *II* Mediterranean.

Gypsum, which is very frequent in the other parts of the Subcarpathian salt formation, is sporadic in the Oltenian one, and plays a secondary part. It comes in the higher part of this horizon of salt formation: at Licura (Stoenesti), Pausesti (Otasau), Barbatesti (Figs. 8 and 9) and Lacul Buha, and occurs as repeated layers between the marls and clays in relation with the bituminous limestones and marls. It everywhere undergoes changes, being dissolved or decom-

posed and forming sulphur. At Pucioasa[1] (Pausesti de Otasau), however, I believe that some small and beautiful gypsum crystals occurring in intercalated marls, soaked with SO_2 and water, have been formed recently. The gypsum from this horizon in Galicia, Podolia, etc., was classified by the Polish, Austrian, and Russian geologists[2] as belonging to the deposits from the *II* Mediterranean Sea. At Barbatesti I found blocks of *Leithakalk* in the neighborhood of the gypsum bed, and although the limestone does not occur as a bed, I think that the two formations belong together, the Leithakalk being immediately above the gypsum.

Salt and Petroleum.—The salt formation of Oltenia contains one salt massif only, but a very large one, 7^{km} long, from Teiusu up to

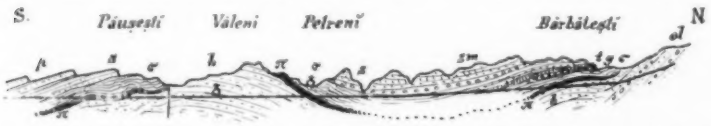


FIG. 9.—Profile of the Otasau valley. (The letters represent the same formations as in Fig. 4.)

g = gypsum bed.

Ocnele Mari. It is not possible to see the width, because the formation is inclined, the depth being more than 300^{m}. It is the only salt massif in Roumania which shows the *Jahresringe* of anhydrite. It very often contains charred wood and nuts (walnut). A piece of amber is mentioned also as occurring here. The composition of the best quality of salt is up to 99.8 per cent. NaCl, the second quality contains up to 2 per cent. impurities, viz., $CaCO_3$, 0.8 per cent.; calcium sulphate, 0.9 per cent.; and water, 0.35 per cent., according to the analysis by Dr. Istrati, Popovici Max.[3] Salt wells occur

[1] See my description of that locality in *Zacamantul de Sulf de la Varbilau*, by L. Mrazec, Mem. Assoc. de Sc. II. Roum., 1904, and Analele Acad. rom. 1905.

[2] Besides the interesting discussions about gypsum, and the Mediterranean deposits in general, by Teisseyre, "Bakauer Karpathen," *Jahr. d. k. k. geol. Reichsanstalt*, 1897; *Atlas géologique de Galicie*, VIII, 1900, etc.; by I. Simionescu, "Tarmul Prutului; Geologia Moldovei intre Siret si Prut," "La Géologie de Moldavie" (*Annales scient. de l'Univ. Iassy*, 1903). I mention the valuable description and general review of this stage and gypsum in general by G. Mikhailowsky, "Die Mediterran-Ablagerungen von Tomakowka," *Mémoires du Comité géolog.*, XXII, 4, 1903.

[3] See the description of Mrazec and Teisseyre, *loc. cit.*

frequently in Oltenia as in the eastern salt region; they are arranged along three lines: (1) Daesti-Bogdanesti-Cacova-Dobriceni; (2) Ocnele Mari, Mt. Slatiora, Pausesti (de Otasau), Folesti, Otasani Aninoasa; (3) Teiusu, Petreni, Tomsani.

They are accompanied by emanations of hydrocarbons. At Cacova we see a *Ferbe* (boiling) of natural gas, but no mud volcanoes. These emanations of petroleum gas come probably from the next oil-bearing strata, the greater number from the Burdigalian formation, the lower salt formation which shows an indication of liquid petroleum. Although the upper salt formation is both eroded, folded and faulted, and the anticlines are eroded down to the lower horizon, no trace of liquid petroleum is to be seen. At Pausesti (Otasau) many wells, and two borings of 327^m and 87^m, were made; there was considerable escape of natural gas from below (from Burdigalian), but no petroleum; however, the work was neither good nor careful, otherwise petroleum would have been found; just as at Govora Spa the administration extracts quantities of petroleum from an iodiferous well bored in the lower horizon (Burdigalian) of the salt formation. The upper horizon of the salt formation in the Pausesti boring was 181^m thick; gypsum was met with at 56^m.

E. THE TORTONIAN STAGE

Sabba Stefanescu and K. Redlich[1] have studied Tortonian deposits from the skirt of the mountains, but they did not mention them as occurring in the salt region. In the above description I have considered as *II* Mediterranean deposits some sandstone conglomerates, dark or bluish, porous limestones, and marls, which alternate with the argillaceous marls in the uppermost horizon of the salt formation. Everywhere, where they occur, they smell very strongly of hydrocarbons. On the hill between Bunesti and Stoenesti they can be well observed; they alternate with marls and thin strata of palla, and contain a small quantity of the elements of palla in their composition (Fig. 8). At Govora (spa and monastery), Pausesti (Otasau), Lacul Buha, and Bistrita they contain gypsum, or come into closer relation with beds of it. These bituminous marls and limestones correspond to the *Nullipora* limestone strata which accompany the gypsum of the

[1] *Loc. cit.*

II Mediterranean deposits in the east of the Carpathians (Galicia, Podolia, Bessarabia, and Moldavia).[1] K. Redlich has described the Tortonian deposits of Cernadia and Polovragi at the skirt of the mountains. He found at Cernadia two horizons: (1) Tegels with a rich fauna: *Ostrea cochlear* Polli, *Pecten*, cf. *Reussi* Hörn, *Nucula nucleus* L., *N. Mayeri* Hörn, *Corbula gibba* Olivi, *Turritella bicarinata* Eichw., *T. turris* Bast., cf. *terebralis* Lam., *Trochus* sp., *Natica helicina* Brocc., *Risoa Lachesis* Bast., *Ringula buccinea* Desh., *Mitra recticostata* Belt., *M. striatula* Brocc., etc. (2) Above these tegels come conglomerates and limestone banks with a Leithakalk fauna: *Lithothamnium ramosissimum*, *Alveolina melo* d'Orb, *Cerithium rubiginosum* Eichw., *Monodonta angulata* Eichw. *Pectunculus pilosus* Linn., *Conus ventricosus* Bronn., *Vermetus intortus* Lam., *Rissoina pusilla* Brocc., *Cypraea* sp., etc., etc.

Both horizons belong to the Upper *II* Mediterranean deposits, equivalent to the Leithakalk of the Vienna basin, or to the deposits of Steinabrunn. Representatives of one or the other horizons I have found at Baia de fer, Racovita, Barbatesti, eastward from Cernadia, and in the Scarita ravine, Radosi, Carpinis, Crasna,[2] etc., westward from Cernadia, always along the skirt of the mountains. The Leithakalk facies is, however, better represented and developed. The blocks which I have found above the gypsum at Barbatesti contain a numerous fauna and are identical with those of Cernadia:

Vermetus intortus Lam.	*Nucula nucleus* L.
Trochus cf. patulus Brocc.	*Chama* sp.
Pecten sp.	*Lithothamnium ramosissimum*,
Pholas sp.	etc., etc.

The Leithakalk and conglomerates do not, however, seem to form a horizon separate from the marly facies, but only a local phenomenon occasioned by the conditions of the sea and the coast. Westward from Jiu valley the *II* Mediterranean deposits were studied and figured by Sabba Stefanescu (Sketch 1). Dobrita and Suseni are points favorable for studying it. At Suseni especially above this complex of conglomerates and Leithakalk there comes a bank of

[1] See footnote 2 above, and L. Mrazec and Teisseyre, "Salzvorkommen in Rumänien," *Zeitschrift für Berg. and Hüttenwesen*, 1903, p. 17.

[2] Some of these localities are described by L. Mrazec in "I Partea de E a Muntilor Vulcan," *Bul. Soc. Ing. de mine*, 1898.

Sarmatian conglomerates with a rich fauna, and above that an oölitic limestone with *Congeriæ* and *Neritina*, perhaps Mœotic strata.

In general, along the skirt of the mountains from Barbatesti up to Baia de Arama we meet with a thick, persistent bed of conglomerates, shingles, and sand, in which we can determine Tortonian strata in some parts; in others, higher up, Sarmatian; and in others still, strata probably Pliocenic containing *Unionidae* and lignite layers. We must admit, then, that these conglomerates at the skirt of the mountains, with the character of cones of dejection, took their rise in the Tortonian and ended in the Pontic age.[1] I have mentioned that the Leithakalk does not form a separate horizon in the Tortonian deposits, but has been formed whenever the character of the sea

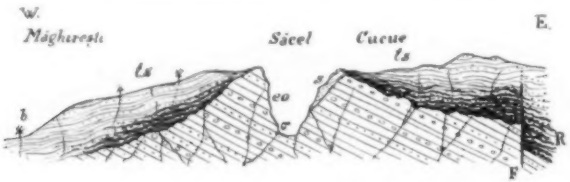


FIG. 10.—Section of Eocene island of Sacel.

eo = Eocene conglomerate and grit; *σ* = salt spring; *ts* = conglomerate and limestone from Tortonian into Sarmatian age; *R* = *Lithothamnium* and *Serpula* reef; *s* = unconformable sand and conglomerate in the lagoon of the Sarmatian Atoll; *b* = (boiling) hydrocarbon emanations; *F* = fault.

beach of the *II* Mediterranean Sea has been favorable. The Tortonian and Sarmatian conglomerates contain very many bones of large vertebrates, which perhaps have been brought down by water from the continent.

The most interesting point of the *II* Mediterranean Sea is at Sacel (Fig. 10).

We have noticed above that in the Blahnita valley there arose an Eocene island; the Blahnita, a small river, cuts this island right through the middle, and through the part which is at present the broadest and highest, thus exposing a very instructive geological section. We see to the north of the spas, and also to the south of the island in Valea Dracoaia, *Lithothamnium* limestone and conglomerates which are like those from the skirt of the mountains, and which cover

[1] F. Toula has emphasized their resemblance to "Belvedere Schotter," of Pontic age. *Jahrbuch für M. & G.* 1897.

the Eocene conglomerates unconformably. Around the Eocene island we see the Lithothamnium formations in the ravines which cut through the Sarmatian deposits down to the Eocene beds. On the summit of the Eocene island I found sandy limestone and conglomerates with casts and moulds of fossils, indeterminable, probably *Tapes*. The beds which cover the island are certainly Sarmatian, because they are the prolongation of conglomerates, sandy and marly beds, in which Sabba Stefanescu[1] and myself have found many Sarmatian fossils. Besides the fossils obtained by Sabba Stefanescu, Professor Laskareff has determined, from my collection, *Tapes gregaria* Pt., and *Mactra fragilis* Lask., and concludes that we are dealing with the lower Sarmatian. These fossiliferous beds at the bottom of the valley do not lie directly on the Eocene conglomerates, so that the inferior marls, conglomerates, and dark *Lithothamnium* limestone may be Tortonian, as indicated by the facies. The structure and arrangement of the formations around the Eocene island are the same as those described both for old and recent coral reefs,[2] corresponding in particular with the formations "Miodobaren" of Galicia, "Toltry" of Podolia, and Stanca of north Moldavia.[3] We have, in short, around the Eocene cliff of Sacel a coral reef which began, like "Miodobaren," to form in the *II* Mediterranean Sea, and continued to grow in the Sarmatic. The lower layers, where they can be seen, are inclined quaquaversally: the higher strata, viz., sandstone, conchiliferous limestone, marls, with leaves of trees and bones of vertebrates, form an anticline, the core of which is composed of Eocene conglomerates. Northward we find, as shown by Grégoire Stefanescu[4] a syncline, followed by an inconsiderable anticline (Fig. 2). If we take into account the great amount of erosion of the Eocene beds before the Sarmatian deposits, and the very complicated outline of the Paleogenic island, which is covered

[1] "Sur l'âge des conglomérats de Roumanie," *loc. cit.*

[2] I mention here the valuable recent work by Saville Kent (Barrier Reef of Australia, 1893); Grabau (Paleozoic coral reef, 1903); Agassiz (Pacific c. coral reef, 1903). Branner (stone reef of northeastern Brazil, 1904); Funafuti (atoll, 1904); Skeats (dolomites of Tyrol, 1905).

[3] The extensive literature about these formations is summarized by Simionescu on the occasion of his study of Stanca, "Sur la géologie de la Moldavie," *Annales de l'Université de Jassy*, 1903.

[4] *Loc. cit.*, Bull. de la Soc. géol. de France.

by limestones and conglomerates, and more particularly by a deposit occurring in some small old valleys, and consisting of sand and conglomerate, quite unconformable both to the Eocene strata, and also to the Tortonian and Sarmatian beds, we come to the conclusion that there was at this point a little *atoll of Sarmatian age.*

This enables us to explain why the Blahnita, a small river with little water, was able to cut its way right through the widest part of the very hard silicious sandstone and conglomerates of Eocene age. Other geographical facts can be similarly explained.

The coral reef extends toward the east, where it is covered by later deposits, but at Bircei-Ciocadia it stands up from the eroded sandstones and marls as a high rock 4^{km} in length, consisting of a cavernous limestone with pockets and lenticular intercalations of sands and sandy marls, and seldom showing any organic structure such as *Lithothamnium.* At Ciocadia, however, the whole rock is filled with tubes of *Serpula gregalis;* the limestone banks have here a lenticular form, and at some points end abruptly, limited by the undisturbed Sarmatian layers. We notice that the rock is identical with that of Toltry and Stanca in the north of Moldavia. The overlying sandstones and marls contain a middle Sarmatic fauna; underneath all this, in a ravine, hard, bluish, sandy marls were found, which alternated with bituminous marls, and in which I collected many tubes of *Serpula* and two petroleum-blackened fossils, probably *Ervilia.* We should thus have here the lowest horizon of the Sarmatian strata, and, if so, the beds underlying the coral reef would be Tortonian, as in the similar reefs in Podolia and Galicia.

The *petroleum* which comes out here from under the coral reef, the emanation of natural gas (at Bircei, Valea Dracoaia, Maghiresti, etc.), and the mineral springs come probably from the Paleogenic island from which the Tortonian conglomerates, and also the cavernous limestone, have imbibed the hydrocarbons. The occurrence of petroleum at Bircei is one of the most interesting in Oltenia.

F. THE SARMATIAN STAGE

The formations belonging to this stage are well developed, and are considered by Gr. Stefanescu (with determination of fossils by Fontannes), by Sabba Stefanescu, apropos of the discussion about Sacel, and also by K. Redlich. I have found these deposits extend-

ing over a large surface in the Olt region, and also as lumps or patches on the salt formation of that region, and as a belt along the skirt of the mountains, where it can be seen in the valley wall of the rivers which have eroded the upper strata. Its occurrence around Sacel, with characters of great interest, has been mentioned above.

In several places organic remains have been found, and from the fossils in my collection Professor Laskareff has been able to distinguish three horizons, as in the south Russian Sarmatic:

1. The lower horizon begins as a continuation of the marly facies of the salt formation; there are: bluish or grayish marls and clays, banded or compact, forming thick beds with small intercalations of sandstones. In the highest beds sandstone with sand and calcareous banks, and a few conglomerates, prevail. Here and there (Ramnic-Valcea-Pausesti, Suseni) there are bands of yellowish oölitic limestone. In the Olanesti valley, Sacel, and Voitesti we find round sandstone concretions, as described in the Sarmatian of Moldavia, Bessarabia, etc.

a) The lowest layers in which I have found fossils are a thin sandstone stratum intercalated between the green marls from the northeast of Ramnicu Valcea, and overlying the levigated palla on the Oltu bank.

Cardium lithopodolicum Dub. *Hydrobia Frauenfeldi* Hörn
Trochus sp. etc., etc.

In the green, banded marls which contain *Lithothamnium* nodules and veins, and which overlie the salt marls from Dobriceni in the Drogu ravine, and underlie the sand and sandstone banks from Smeuretu-Stoenesti, there occurs *Syndesmya*, cf. *apelina* Ren.

At Titireciu, in a ravine cutting the folded salt marls and sand which have a well-marked salt efflorescence, and which lie immediately above a bed of levigated palla (Fig. 8), I found in an intercalation of sand: *Ervilia* cf. *pusilla* Phil., *Congeria* cf. *Sanbergeri* Andr., etc.

Ervilia pusilla denotes the lowest Sarmatian strata, the transition from Tortonian to Sarmatian—a stratum described exhaustively by Professor Laskareff at Buglowo[1] (southern Russia). Accordingly,

[1] W. Laskareff, "Die Fauna der Buglowka Schichten in Volhynien," *Mémoires du comité géologique*, Nouv. Série 5, 1903. Perhaps the limestone with *Tapes vitaliana* from Lacul Buha belongs also to this horizon.

the levigated palla would be Tortonian, as would appear also from the evidence given above; and, what is still more interesting, the *salt facies of the Oltenian Tertiary extends upward to the lower Sarmatian.* Sarmatian layers with salt facies were mentioned also by Mrazec and Teisseyre in Distr. Prahova, Ramnicul sarat, Bacau, etc.

b) Besides the above localities, the lower Sarmatian was identified in the sandstone facies at Buda, Inotesti, Pausesti de Olanesti,[1] Negoesti-Petrari, Viezure, Tomsani, Govora, Sacel, etc.; it is a horizon (Volhynian according to Simionescu) well characterized in Volhynia, Moldavia, and Bessarabia, etc., by *Ervilia podolica* Eichw. At various localities in this horizon I collected the following fossils:

Mactra fragilis Lask.
Modiola marginata Eichw.
Modiola volhynica Eichw.
Cardium protractum Eichw.
Cardium obsoletum Eichw.
Cardium plicatum Eichw.
Cardium lithopodolicum Dub.
Cerithium disjunctum Sow.
Cerithium rubiginossum Eichw.
Cerithium mitrale Eichw.
Corbula sp.
Spirorbis sp.
Ervilia podolica Eichw.
Buccinum duplicatum Sow.
Trochus sp.
Melanopsis impresa Kraus.
Serpula spiralis Eichw.
Hydrobia sp.
Dentolina
Modiolae (Small)
Gastropods (Small)
etc.

The stratum which contains these fossils is always higher than that described under *a*).

2. The middle Sarmatian (Bessarabian Sim.) is represented by beds of sandstone, sand, and conglomerates with shales, at Stoenesti, Buleta, Dianul (S. de Slatioara), at Marita determined by Redlich, Racovita, Polovraci, Ursani, Baia de fer, Novaci, Sacel, Surpati, and at Ciuperceni (in Oltetu valley), determined by Fontannes,[2] and is characterized by *Mactra Fabreana* d'Orb., *Tapes gregaria* Partsch, etc. I may here mention the conglomerates from Crasna, Suseni, Dobrita, at the skirt of the mountains which contain:

Cardium protractum Eichw.
Cardium lithopodolicum Eichw.
Modiola marginata Eichw.
Syndosmya reflexa Eichw.

[1] Fontannes mentions some Sarmatian fossils from Ramnicul Valcei, Episcopia, Cetatuia, Glimboaca, etc.: "Faune malacologique tertiaire de Roumanie," *Archives du Muséum d'Histoire naturelle*, Lyon, 1886. From Episcopia (Roumicu Valcei) he described *Tapes gregaria* var. *Ramnicensis.*

[2] From here comes *Mactra Stefanescui.*

Mactra Fabreana d'Orb.
Mactra fragilis Lask.
Mactra Neritina sp.
Morenstermia inflata Andr.
Serpula gregalis,
etc.

This horizon of the Sarmatian penetrates also into the Mehedenti Plateau at Tismana, Sohoholu, Baia de Arama, etc. At Tarnita (Baia de Arama) I found *Cerith. mitrale*, which demonstrates that the upper beds of the conglomerates, considered by Sabba Stefanescu to be Tortonian, must in part be classified as Sarmatian.

3. The upper horizon (Kersonian Sim.) consists of sands, sandstone and argillaceous marls; it is not rich in fossils. At Buleta, in calcareous conglomerates and conchiliferous limestone, I have found: *Mactra caspia* Eichw., *M. bulgarica* Toula, *Cerithium disjunctum* Sow. cf. *Constantiae* Sabba, *Cardium* sp., *Hydrobriae*, and *Dosinia exoleta* L.

It is interesting to note that in the conglomerates and conchiliferous limestone at Titireciu there occur also *Dosinia exoleta* and *Modiola Volhynica* Eichw., *var. minor* Andr., etc., etc., which would indicate the first appearance of the Mœotic stage in this country.

Toward the west I have found no evidence for the extension of the Mœotic assise in that direction. Possibly the beds with *Helicidæ* between the strata with brackish and subbrackish fossils, and the strata with *Valenciennesia* and *Limnea*, belong to the Mœotic stage; in Mehedinti similar marls with *Globigerinae* and *Orbulinae* were classified by S. Stefanescu and Fuchs as Sarmatian.

In the middle and upper horizons of the Sarmatian (Aninis, Sacel, Buzesti, Surpati, etc.) many plant remains[1] and bones of vertebrates have been found.

The mineral springs which appear in the Sarmatian at Pausesti, Costesti, Ramnic, Polovraci, Novaci, Maghiresti, Balanesti, etc., owe their salts and H_2S to the pyrites and other minerals which occur among the shingle of the Sarmatian conglomerates and sand, just as is the case in the Eocene conglomerates. The emanations of natural gas in the Dracoaia valley, Maghiresti, etc., are very probably derived from the oil-bearing Eocene or Tortonian substratum.

[1] Some remains of plants collected by Gr. Stefanescu in this region were described by A. Marion and L. Laurent (*Annuaire du Musée de Géologie et Paléontologie*, 1895).

G. THE PONTIC STAGE

While we find Pontic formations with a well-marked fauna, northward from the Slatioara anticline, it would appear that they do not exist northward from the Ocnele mari anticline. At Fundatura, Smeuretu and Cacova we meet with some thick shingle beds without fossils and with a torrential character. They lie on top of the conglomerates with shales and conchiliferous limestone of Titirecciu, in which I found *Dosinia exoleta* and *Modiola volhynica* var. *minor*, indicating the uppermost Sarmatian, perhaps the Mœotic, so that, at all events, the highest shingle may be Mœotic or perhaps Pontic, but without certainty. To the west of the salt region the Pontic beds, after forming a bend around the Magura Slatioara island, are prolonged eastward as a gulf extending up to Bistrita Massif and the Carpathian Mountains. As to facies, the Pontic deposits are very variable. Along the skirt of the mountains and at Magura Slatioara they retain the facies of the cones of dejection, as did the Tortonian and Sarmatian deposits. It is of interest that in the lower strata of the Pontic, at Coada Magura, in the sandy marls intercalated between conglomerates and shingle, I have found *Helicidae*, which would indicate the presence of dry land in the vicinity. Teisseyre and others consider the *Helix* layers as Mœotic.

Southward from Slatioara we have a uniform zone of yellow sand, with greenish or bluish marls and clays, and a seam of lignite, etc., which comes from the east, from Arges, and runs westward parallel to the skirt of the mountains, right up to the Danube in Mehedinti. In the Subcarpathian region, from Horezu westward up to Baia de Arama and even farther, the facies of marls, with small sand beds as bands, is the predominant one. At Novaci, Aninis, Porceni, etc., along the skirt of the mountain, we can convince ourselves that this facies is the somewhat distant continuation of the sand and shingle conglomerates of the cones of dejection. This is an important fact which explains to us the orographical and hydrographical conditions under which these formations, and the similar ones in the Sarmatian salt formation and even Burdigalian strata, have been deposited.

The thickness of this facies is enormous, and constant in the Jiu valley and west of it. All the rivers—Gilortu, Jiu, Bistrita, and their affluents—have cut their beds deep into this formation. At

Targu Jiu a well was bored 250^{m} deep, and only fine banded marls were found, without any other rock, lower layers not being reached. Through the whole of its extent this facies contains very many *Cypris* and small *Hydrobiae*, and traces of plants, especially algæ. In such deposits, or in their representatives among the conglomerates, I have found *Unionidae* and *Congeriae* in several localities, where Sabba Stefanescu and Redlich and I have also found *Mactrae* and *Modiolæ*, etc. Sabba Stefanescu has emphasized the fact of the mixture of the Sarmatian marine fossils with fresh-water species;[1] and I agree with Andrussow and Laskareff in thinking that also in Oltenia the transition from the Sarmatian beds to the conformable Pontic ones is through the Mœotic layers.

Westward from Oltetu I have found, in the lower marls and sand, the following characteristic Pontic fossils: *Valenciennesiae*, *Limneae*, and transition forms; then *Congeriae*, *Zagrabica*, *Dreissensidae*, *Cardii*, etc. (at Piticu, Pociovalistea, Huluba, Balcesti, Turbati, Targu Jiu, Dealul Targului, Barzesti, etc.). Among the marls there is a small bed or lenticular pocket of sand containing pyrites, which becomes changed, forming sulphates (gypsum, melanterite, epsomite, etc.) and iron oxides, etc.

Iodine and mineral water also come from these beds. In the highest horizon of the marls we find *Cardium Riegeli* Hörn., *Prosodacnae*, etc. (Bengesti-Scoarta-Zorlesti, etc.).

Eastward of Bengesti, up to Oltetu (Zorlesti, Sitoaia, Igoiu, etc.), the Pontic layers form a very flat anticline; there are deep banks of sand and shingle, sandstone and grit with *Congeriae* and *Planorbis*. Above this complex we have a bank of oölitic limestone full of *Neritinae*, *Unionidae*, *Congeriae* (and *Dreissensidae?*), etc. A similar oölitic limestone with *Neritinae* can be seen at Suseni above the Sarmatian conglomerates.[2] Above the oölitic limestone we find sand and marl beds at Negoesti-Rosia-Igoi, etc.; and then comes the lignitiferous zone with *Vivipara bifarcinata*, studied by Fontannes at Cucesti and Turcesti, Genuneni, Folestidejos, Berbesti, and by

[1] *Palæontologie*, Vol. II.

[2] This horizon resembles closely, as facies and fauna, that described as Mœotic by W. Teisseyre in the Buzeu district, *Verhandlungen d. k. k. geol. Reichsanstalt*, 1897. I am awaiting the determination of Professor Laskareff, which will solve the question.

S. Stefanescu at Seciurile, etc. At Cucesti and Slatiora I collected a fauna which was investigated by Professor N. Andrussow, who was good enough to communicate his results to me. He found:

Dreissensia tenuissima Sinz	*Neritinae* sp.
Dreissensia Berbestiensis Font.	*Prosodacua Munieri* Sabba.
Prosodacra littoralis Eichw.	*Didacua placida* Sabba.
Vivipara bifarcinata Biettz.	*Limnocardium aff. ochetophorum.*
Vivipara Woodwardi Brus.	*Pyrgula aff. Siuzowi* Andr.
Vivipara Sadleri Partz	*Hydrobiae* sp.
Cardidae sp.	*Pisidium* sp.

According to the determination by Professor Andrussow, as he himself expresses it, this horizon contains a fauna with species characteristic of the blue clay facies from Odessa, and also species belonging to the upper layers between the Pontic and *Psilodon* assise. This horizon corresponds to the *II* horizon of the Pontic stage, according to the classification of Professor Andrussow.[1] Fontannes[2] and Sabba Stefanescu[3] classify the zone Cucesti-Berbesti among the highest layers of the Pontic (s. s.) stage, which is in accordance with my observations. Professor Andrussow adds, however:

> I have noted in several places (see in particular the synoptic tables in the Monograph of *Dreissensidae*) that the Roumanian Pontic stage does not quite correspond to the layers which are understood under this name in southern Russia, Austria, Austria-Hungary, and even in Italy. The lowest limit of the Roumanian Pontic—the *Congeria* layers—does, indeed, coincide with that of the south Russian Pontic, but the upper limit in Roumania is much higher than that between the Pontic and Levantine stages in Hungary and the southern Slavonic countries. Accordingly, the upper part of the Roumanian *Congeria*, or better *Cardium* layers, which are called Pontic by many authors, correspond to the deposits which in other districts are classified as Levantine.

Southwest from Slatioara, on the highroad near Cerna, and at Cristanesti (north of Cucesti), I found in the marls an intercalation of sandstone and sand which, like the horizon from Bengesti, contains many fossils: *Cardidae, Prosodacnae, Dreissensidae, Hydrobiae*, etc.

[1] N. Andrussow, "Excursions dans la presqu'île de Kertch," *Guide géol. du VIIe congrès géol.*, St. Pétersbourg, 1897, Fas. XXX; *Die Neogen-Ablagerungen S. Russlands*, 1901 and 1903.

[2] Fontannes, "Contrib. à la faune malacologique des terrains tertiaires de la Roumanie," *Arch. du Muséum d'Histoire naturelle de Lyon*, Tome IV (1886).

[3] S. Stefanescu, *loc. cit.*, "Etage pontic."

In the Cerna, under the bottom of the river, the complex of marls and sandstones, many banks of alternating sandstone and marls may be seen which contain beautiful leaves of trees and *Helicidae* and *Planorbis*. I may add that these strata are very probably the continuation of the sandstone and oölitic limestone with rich mentioned fauna of the Sitoia anticline. These banks would correspond either to the *Valenciennesia* strata, or, according to Andrussow and Teisseyre,[1] to a formation which in other localities lies on, or is in continuity with, the Upper Mœotic assise. These *Helicidae*, and those from Coada Magurei, would indicate a former dry land in this region.

The corresponding strata at Slatioara and Cucesti were bent into an anticline above the Slatiora island (Figs. 3, 5, 6); a part of the Pontic strata were thrust over the folds of the salt formation. The anticline produced toward the southwest can be made out in the Oltetu valley at Nicoresti-Cursoru, etc.

1. *Andesitic tuff of Gantulesti.*—Of great importance for the Pontic petrography of Roumania is the occurrence of a lenticular bank of andesitic tuff at Gantulesti, between Madulari and Armasesti. The rock is porous, fine-grained, with sedimentary Schlieren, and with pseudo-Kaolinitic patches like the pseudomorphs of an unknown vanished mineral. Prismatic crystals of basaltic hornblende are scattered throughout the whole mass of the rock, while the glittering crystals of bytownite occur only in the white patches. The groundmass is constituted by microscopical glass lapilli, and small crystals of hornblende, bytownite, augite, olivine, etc., show shining crystal faces (110, 100, 101, 111, etc.), and form twins; and while the crystals of both are much cracked, we can still separate perfect ones up to 2^{mm} in length.

By mixture with sedimentary elements, the tuff receives a water sediment facies, and becomes sandy or marly.

The bank of tuff, about 1^{m} broad, runs eastward from the high-road some 100^{m} before it terminates; westward it crosses the river Cernazioara, and then is lost to sight because of the wood. Immediately above it we find marls and sands with *Neritinae*, large *Hydrobiae*, *Vivipara Woodwardi*, *Unionidae*, *Cardidae*, etc., which corre-

[1] W. Teisseyre, "Die Helixschichten aus Buzau Distr.," *Verhandlungen d. k. k. geol. Reichsantalt*, 1899.

spond to the horizon from Bengesti-Cristanesti, underneath the lignite zone of Cucesti-Berbesti-Seciuri.

2. *The origin of palla and andesitic tuff.*—The same question arises here as in the consideration of the occurrence of palla. The structure of the tuff, unchanged for the most part, and the fact that the very fragile crystals are still perfect and undisturbed, are proofs that these rocks could not have been carried by water. It must have appeared at its present site, and undergone a redeposition at its upper surface only. Accordingly, there must have been volcanic activity in this region at the end of the Pontic age, just as we find in Transylvania, where andesites appear in the upper Sarmatic and Pontic strata. It is curious, however, that no other sign of volcanic activity can be found here, except possibly the hot spring at Bivolari, and some SO_2 emanations at Pausesti, Maghiresti, etc. Probably the volcanic region was more to the south, so that its products and remains were covered by later depositions from the Pontic and Levantine lakes. If we admit the existence of a volcanic activity in Oltenia, as in Transylvania, in the Tertiary period, we can explain the occurrence of the palla which occurs in such quantities at the convexity of the bend of the south Carpathians.[1] Professor Mrazec has described a well-preserved andestic tuff from the Bacau district, not, however, found in situ, but very interesting from our point of view. Professor Laskareff states that in my specimens containing fossils which come from Sacel, Buleta, etc., in the lower and upper Sarmatian, there are constituents of the material thrown out by a volcano. Accordingly, it is possible that in the concavity of this west bend of the Carpathians, Tertiary eruptions could have taken place, just as in Transylvania and in east Servia (Timoc valley).

3. It may be of interest to mention some other geological phenomena in relation to the Pontic deposits, particularly the marls:

a) Mineral springs at Balanesti, Pociovalistea, Ciocadia, Putul Balanescu, etc., whose origin from mineral containing sands I have mentioned above.

[1] To explain this palla, Professor Mrazec assumes a possible connection between the salt formation from Transylvania and Moldavia through the Oituzu valley, but he observes exactly in this region that palla is wanting. A connection between Transylvania and Oltenia in the Pliocene age is less possible; but I must add that in east Servia, in the Timoc valley, dacite tuffs in the Mediterranean deposits were described by Zujovic (*Annales géolog. de la péninsule Balcanique*, 1900), etc.

b) Some mud volcanoes, the largest being at Serbesti, Basnesti Novaci, Tetila, etc. The numerous *gloduri* ("muds"), mud volcanoes in miniature, are phenomena related to those of natural gas; they occur along three lines: (1) Cernadia-Carpenis-Tetila; (2) Pitic-Pociovaliste-Turbati-Lazaresti-Tetila-Arcani, Bala, etc.; (3) Zorlesti-Balanesti-Preajba-T. Jiu, etc.

c) Natural gas at Balanesti, T. Jiu, Barsesti, Lazeresti, etc.

d) The occurrence of many beds of a red shale, natural brick or quite black or brown, porous hard stone like artificial basalt. They come in the immediate vicinity of the lignite seams, and are produced by the spontaneous burning of the lignite.

e) Petroleum occurring in the highest layers at Balteni (Gorj) in the strata with *Vivipara bifarcinata* (*loc. cit.*).[1]

The petroleum emerges from sand and gravel beds in the Valea Pacurei ("Tar Valley") and at Lacul Sarat ("Salt Lake"), and has been worked many years ago. These oil layers are quite isolated from any other oil-bearing deposits or older formations: They have as underlying, thick banks of sand and marls, and also the lower marl horizon with *Valenciennesia* more than 250^{m} thick. They are inclined at 15° toward the south-southeast, and prolonged eastward and westward over the whole of Oltenia. Neither a fault nor an important fold was observed in this horizon.

There are two ways of explaining the occurrence of Balteni oil:

(1) An underground infiltration from Paleogene or lower Miocene oil-yielding layers. Petroleum was found in the strata with *Vivipara bifarcinata* elsewhere also, and, for example, the Baicoi-Tintea-Gura Ocnitei zone (with a production of 7 per cent. of the whole production of Roumania). There petroleum was explained by L. Mrazec and Teisseyre as being in a secondary bed; it may be possible there, because that region is very folded and faulted, and the underlying Mœotic assise is very rich in petroleum (87 per cent. of the production).[2] The Pontic region of Gorjiu is, however, undisturbed. An infiltration could be only through the southern end of the Pontic assise; in this case, why should not petroleum occur also in the

[1] Described by Gr. Stefanescu, together with some of the mineral springs of this region.

[2] Les travaux de la commission du pétrole, I, 1905.

lower strata of the Pontic stage? Balenescu at Targu Jiu, and Daniilescu at Barzesti, have made two borings (250m and 80m) into the Lower Pontic; strong emanations of hydrocarbons were observed, but no petroleum.

(2) This petroleum may be in relation to the repeated underlying seams of lignite and the beds which are very rich in molluscan fauna. The lignite often burns spontaneously; at Turcesti, Rosia (Valcea), Rosia Amaradia (Jiu), Negoesti, etc., it is continually burning. Some seams of this lignite are very bituminous; when they burn, they increase from seven to ten times in volume, and they smell of bitumen from afar; through their heat the adjoining shale and sandy marls, etc., are burned and metamorphosed.

In general, the phenomena are similar to those described from the Californian oil region (Santa Barbara), but the metamorphism of the red shales, brown and black stones (like basalt or jasper), etc., of Oltenia is obviously due to the burning of lignite.

I hope that the vegetable theory accepted and developed by Zuber[1] for the north Carpathian oil regions will receive a contribution by means of these facts of Oltenia. The gaseous hydrocarbon from the Lower Pontic could have their origins in the large quantity of algæ, plant, and fish remains which are abundant in the *Valenciennesia* strata. The oil from the upper strata arose, very probably, from the distillation of organic substance of the molluscan beds and lignite seams, by the burning of lignite.

H. THE LEVANTINE STAGE

The Levantine formations which occur to the south of the Subcarpathian region have been studied exhaustively by Fontannes, Fuchs, Tournouëri, Porumbaru, Sabba Stefanescu,[2] etc.; accordingly I did not presume to repeat their observations. L. Mrazec[3] has described a Levantine terrace along the skirt of the mountains westward from Jiu; east of this valley it is not well marked. According to the orography (terraces and peneplanes) in the high mountains

[1] R. Zuber, "Kritische Bemerkungen über die modernen Petroleum-Entstehungs-Hypothesen," *Zeitsch. f. prakt. Geologie*, 1897, 6.

[2] See the discussion of this stage by Sabba Stefanescu (*loc. cit.*).

[3] L. Mrazec, "Les schistes cristallines des Carpathes méridionales," *Comptes Rendus du Congrès géol., IX*, Vienne, 1903.

and high plateau of Mehedinti, it appears that this terrace may be older than Levantine, and may very probably be Pontic. Further it is possible that here, as in the whole Subcarpathian depression, the shingle which covers the highest river terrace, and the eroded ridge of the hills, may be Levantine.

THE TECTONIC OF THE SUBCARPATHIAN REGION OF OLTENIA

1. *General consideration of the Tertiary formations.*—A comparison of the Tertiary formations of Oltenia with those from the east and north sides of the Carpathian Mountains[1] will give us a clear idea of the past of this region.

The Cretaceous and Lower Eocene Flysch shows here almost the same facies and the same relation to older klippes as in the north and east of the Carpathians: a torrential period (Cenomanian and Turonian), with deposits of coarse conglomerates, and coarse shingle consisting of crystalline rocks; a period of comparative rest (Senonian to Middle Eocene), with the deposition of layers of marls and sandstones with *Inoceramus*, corresponding to a period of upheaval of the region; and then another torrential period (end of the Middle Eocene), with deposition of conglomerates and shingle with large blocks of coral limestone with *Hippurites*. The facies of all these formations are similar around the Carpathian bend,[2] the lower horizon corresponding to the Bucegi conglomerates.

[1] I take into consideration this region of the Carpathians, because our region is its natural continuation. The Transylvanian Basin, which is very similar to, and synchronous with the formations of Oltenia, was separated, however, from them by the south Carpathians. Although in the Mehedinti plateau, and in the Carpathians of Banat, Miocene basins are frequent, I believe that an open communication in this direction between the Miocene sea of Banat and Oltenia did not exist; the geologists of Servia (Radovanovic, Pavlovic, etc.) have shown that the Neogene fauna of northern and western Servia, like that of Banat, bears a relationship with the Panonian Neogene one, while the Neogene fauna of eastern Servia (Timoc valley) and Bulgaria is very similar to that of the south Russian Tertiary. The Oltenian Tertiary region is the northward continuation of the Servian, and its similarity with that of Russia has already been mentioned several times in this description.

[2] The explanation of the klippes and Flysch in the north and east Carpathians was given by V. Uhlig. His very appropriate hypothesis has received many confirmations through the researches of the study by L. Mrazec, Teisseyre, Sava Atanasius, Simionescu, etc., in the Carpathians of Moldavia and Muntenia. It is pleasant for me to be able to confirm the fact that the theory of the Carpathian savant is applicable in Oltenia also.

The upper deposits of the Flysch no longer show the same facies as in the east. While the lower strata still show some similarity of fauna, neither the green conglomerates (a local facies in the east) nor the characteristic menilitic schists, or the Kliwa sandstone is seen. I have shown elsewhere[1] that the upper deposits of Muereasca-Olanesti correspond to the Targu-Ocna strata; another point of similarity would exist if my suggestion, that the Eocene layers of Oltenia should have salt and petroleum, should hold.

As for the Miocene salt formation of Oltenia, its similarity with the east and west salt formations, and more especially with the Slanic and Trotus Basins, may be clearly seen from the above. I have shown that the Oltenian salt formations consist of two horizons:

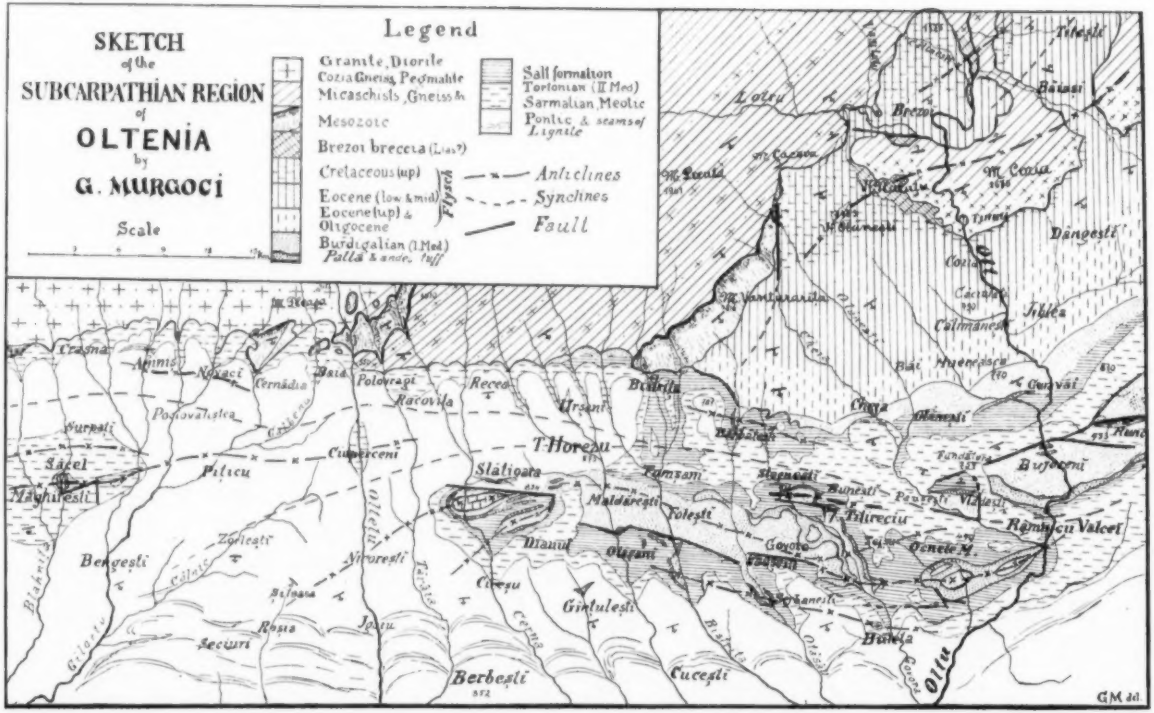
a) Conglomerates, shingles, and sand, with less important colored marls, gypsum, and palla, belonging to the *I* Mediterranean Sea (Burdigalian and perhaps Helvetian in parts). Its constitution shows a coast and lagoon facies, and its relation to the Oligocene layers—in some localities conformable, but in others unconformable—and more particularly the occurrence of water-worn *Nummulites*, etc., are evidence for *the regression of the Flysch Sea, and the beginning of the Mediterranean Sea, at the end of the Oligocene, with other shores.*

The reddish facies of this horizon, with its gypsum and marls, represents a deposition at some distance from land; both facies correspond, as regards position and stratigraphy, with the similar formations of the Slanic Basin.

b) The upper horizon, gray-bluish marls with *Globigerinae*, lies above the Burdigalian in the Oltu valley, and, like the deposits of the Slanicu and Trotus Basins, is a deposition far from the Flysch shore. The palla characteristic for the Subcarpathian Miocene salt formation is represented, perhaps even more abundantly, to the west of the Olt River. It appears with the banded facies of the Burdigalian, and continues up to the upper Tortonian, like that of Transylvania. There are two kinds of palla; a genuine tuff with an eruptive crystalline facies predominant, and a levigated palla, like Trass, with a sedimentary facies predominant, just as was observed in the Slanic Basin.

Gypsum is also represented in Oltenia, and comes in the upper

[1] *Gisements du Succin de Roum.*, 1902.


SKETCH
of the
SUBCARPATHIAN REGION
of
OLTENIA
by
G. MURGOCI
Scale
Legend
Granite, Diorite
Cozia Gneiss, Pegmatite
Micaschists, Gneiss &
Mesozoic
Brezoi breccia (Lias?)
Cretaceous (up)
Eocene (low & mid)
Eocene (up) &
Oligocene
Burdigalian (I Med.)
Salt formation
Tortonian (II Med)
Sarmatian, Meotic
Pontic & seams of Lignite
Flysch
Anticlines
Synclines
Fault
Brezoi
Berbeşti
Ocnele M.
GM del.

layers of the salt formation, very probably constituting a deposit from the *II* Mediterranean Sea, as in Moldavia, Bucovina, and Galicia, etc.

The alternation of the salt marls and palla beds with bluish marls and black cavernous bituminous limestone, perhaps containing *nullipora*, bituminous sandstone, and gypsum, is evidence that the Schlier facies includes the deposits from the *II* Mediterranean Sea, as was suggested by Hilber, and more recently by Mrazec and Teisseyre. On the other hand, the occurrence of salt marls and sand which, near Titireciu, lie immediately on the levigated palla, and which contain *Ervilia pussila*, *Syndosmya apelina*, etc., demonstrates to us the *continuity of the Mediterranean lagunar facies, in Oltenia at any rate, with the lower Sarmatian, the Buglowian assise belonging also to the salt formation.*

But while in the center of this region the marly facies predominates, at the skirt of the mountains we find a very gradual transition to the Sarmatian through the Tortonian, with its alternating layers of limestone and calcareous conglomerates. An important confirmation of this continuity is the retardation of the facies westward. Even the middle Eocene conglomerates and grit of Salatrucu have at Sacel an Upper Eocene fauna, like that of the marl facies of Olanesti. The banded facies of the salt formation is apparently deposited at Barbatesti, Titireciu, Tomsani, and Otasani well into the Tortonian age, and the marl facies appears as part of the lower Sarmatian. Mrazec and Teisseyre have mentioned Sarmatian layers with salt facies (Prahova R. Sarat Bacau), and Ion Simionescu noticed the same behavior for the marly facies which comes under the Moldavian Sarmatian.

There is an obvious conformity between the two salt facies, although there are intercalated beds of palla. At Dianul and Otasani there follows on the salt marl a complex of marls, sands, sandstones, and calcareous marls, and above them all, conglomerates with *Mactra Fabreana.*

If we assume the same geological conditions for the Ocnele Mari Basin as for the Slanic one, the question would arise: What formed the south shore of the lagoon? It could not have been the line between Slatioara and Sacel, because the salt formation occurs also to the south of the Slatioara anticline. The torrential shingle and

conglomerates, however, which near Ocnele Mari-Govora contain eroded and water-worn *Nummulites*, *Cerithium plicatum*, etc., and which are separated from the mountain deposits by a zone of the banded facies 20^{km} broad, could not have been brought from the north; they must have been carried from the south, where, accordingly, there must have been a broad dry land. The reduction in size of the salt formation southward from Slatioara, the occurrence of conglomerates, limestone (with *Lithothamnium*) at Govora, Otasani, and more particularly the coral reef (barrier reef) of Bircei-Sacel, indicate the proximity of the seashore at this point; the presence of *Helicidae* and *Planorbis* at Slatioara in the Mœotic (or Lower Pontic) is further evidence that dry land had again appeared at this time. The absence of the lower Pontic in the Olt region, and the occurrence of the andesitic tuff in the Upper Pontic, show that this dry land extended eastward from Slatioara. At Marculesti (on Baragan) in a deep boring, the Sarmatian has been found resting directly on the Cretaceous. The paleogeographical conditions of this region are represented in Fig. 11.

Accordingly, the Mediterranean Sea must have sent a gulf along the Carpathian Mountains, and later the country to the south of them was covered by brackish and fresh water from the Sarmatian and Pontic to the Levantine age. Slatioara and Sacel formed islands, and east from Sacel various organisms built up a barrier reef, as a prolongation of the Podolian-Moldavian Toltry.

From the Tortonian age on, the Oltenian

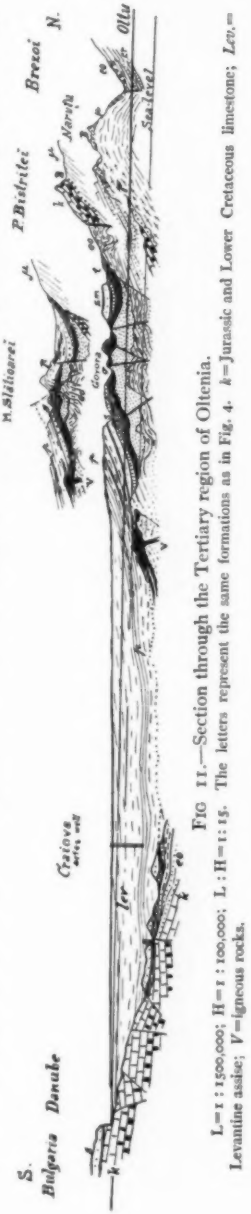


FIG 11.—Section through the Tertiary region of Oltenia.
L = 1 : 1,500,000; H = 1 : 100,000; L : H = 1 : 15. The letters represent the same formations as in Fig. 4. *k* = Jurassic and Lower Cretaceous limestone; *Lev.* = Levantine assise; *V* = igneous rocks.

deposits are almost identical with those from the north Moldova, Bessarabia, and Volhynia. The Buglowian strata, intermediate between the Tortonian and Sarmatian, are, also represented in the Olt region, but with a degenerate salt facies.

The Oltenian Sarmatian is more complete than that from Moldavia; we can distinguish the three horizons which are described in Bessarabia, and Volhynia. The upper Sarmatian is not well developed, and is perhaps continuous with the Mœotic strata (at Buleta there is Kertch limestone). It is of interest to note that where the Mœotic appears, we do not find the Lower Pontic layers, while in the west it runs to a considerable thickness. I may further add that below Baragan only the Upper Pontic is well marked.

I now summarize the above results in the following synoptic table.

2. *Dislocations.*—A consideration of the above geological sections, and an inspection of the adjoining sketch, will give a good idea of the structure and tectonic of the Subcarpathian salt region of Oltenia. We have there a characteristic layer, the palla, which is easy to recognize and to trace, which appears in almost every valley, and which I have attempted duly to emphasize in my sections. Accordingly, a detailed description will be unnecessary. The epochs of movements coincide with those sketched by Sabba Stefanescu in his monograph on the Tertiary of Roumania, and confirmed by L. Mrazec and Teisseyre in subsequent researches.

Between the Upper and the Lower Cretaceous a series of movements and dislocations, similar to that described for the northeastern Carpathians, occurred in the Carpathians of Oltenia. It would seem as if in the southern Carpathians the movements had been more violent and intense; there is evidence to show that that part of the crystalline mountain region north and eastward from Polovragi was thrust over onto the western portion, just as the scales of a fish move one over the other.[1]

The edge of the upper scale would coincide now, after much erosion and dislocation, with the southern skirt of the mountains, the contour of the Mesozoic formations of the mountain region. Magmas coming from below have cemented together the two sur-

[1] See on this question: G. Murgoci "La grande mappe de charriage dans les Carpathes méridionales." *Comptes Rendus de l'Académie des Sciences.* Paris, 1905.

Group	System	Series	Stages & Subs.	Facies	Fossils	Rocks	Oltenia Regions	Elsewhere
Tertiary	Neogene	Pliocene	Levantine					
			Pontic — Upp.	Large Basin	*Viv bifarcinata, V. Abichi, V. Woodwardi*, etc.	Sand, clays, and marls. **Tuff** (andes.), **Lignite Petroleum.**	Lignite zone Tigveni-Cucesti-Berbesti-Rosia-Olteni.	Below Baragan, etc.
			Pontic — Mid.		*Unionidae, Congeriae, Prosodacnae* without *Vipip.*	Oölitic limestone; sandstone, sand, marls.	Voitesti-Bengesti-Sitoaia-Jgoi-Cristanesti.	
			Pontic — Low.	Deep Basin	*Valenciennesia, Limnea, Pontalmira*, etc. *Fishes*, etc.	Marls, little sand and sandstone. Pyrites.	Vaidei-Slatioara-Poenau-T. Jiu-Tismana-Mehedinti.	Istrita (Kertch)
		Miocene	Mœotic	Coast and Lagoon	*Dosinia exoleta, Modiola volhynica, Mactra caspia, Helicidae*, etc.	Conchiliferous limestone (Kertch), conglomerates, coarse sandstones.	Titireciu-Fundatura, Buleta Negoesti-Tomsani.	Podolia / Volhynia / Bessarabia / Prahova / Buzau / East Servia (Timoc Valley)
			Sarmatian — Upp.	Near the Coast	*Mactra podolica, M. Fabreana, Tapes gregaria.*	Sandstones, conglomerates, limestone, marls.	Stoenesti-Negoesti-Dianu, Surpati-Oltet-Skirt of Mt.	
			Sarmatian — Mid.	Deep and Calm Sea	*Ervilia podolica, Mactra fragilis*, etc.	Sandstone with concretions, limestone.	Olanesti Valley, Sacel Rimnicu V.	Moldova
			Sarmatian — Low.	Far from Land	*Syndosmya apelina Ervilia pusila.*	Marls, little sandstone (Tegels).	Titireciu-Dobriceni.	Buglowo / Bucovina
			Tortonian (II Mediter. Sea)	Dejection cones, stone reef, and sea marl.	*Ostrea cochlear, Alveolina melo, Vermetus intortus, Lithothamnium ramosissimum, Pecten*, etc.	Conglomerates, Leithakalk, Gypsum, **Petroleum**? Tegels. **Palla.**	Skirt of the Mountains Sacel. Barloz-Petresti-Govora-Buha-Barbatesti.	Slanic Basin / Trotosu Valley: E. Galicia Podolia
			Helvetian?	**Subcarpathian Salt Formation.** In closed lagoon.		**Salt.** Marls, Sands, **Palla.**	Bogdanesti-Bunesti-Tomsani-Otasau, Ocnele Mari Teisu-Govora-Pausesti.	W. Galicia Transylvania Bahna Petrosani
			Burdigalian (I Mediter. Sea)	Coast and torrent, delta, and far from land.	*Cerithium plicatum, Cerithium margaritaceum*	Conglomerates and shingle. **Palla, gypsum, petrol.** Sand, sandy marls, lignite.	Gua Vai-Olanesti, Bujoreni-Runcu, Ocnele M. Govora-Statiora.	
	Paleogene	Carpathian Flysch	Oligocene	Coast and torrential	*Nodosaria latejugata, Cerithium umpulosum.*	Sands, sandstones, and conglomerates.	Muereasca de jos. olanesti.	N. and E. Carpathian Basins / B. of Glodu, Stamiscara, etc.: Tirgu Ocna assise
			Eocene — Upp.	Deep, far from the coast	*Nummulites Boucheri, N. Tournouëri, N. Budensis.*	Marls and sandstones, **amber, petroleum, salt?**	Northward from Daesti-Mueraesca Cheia.	
			Eocene — Mid.	Very torrential	*Operculina ammonea, Num. Lucasana, N. perforata.*	Conglomerates, grits, etc. (Blocks of Hippurites limestone.)		
			Eocene — Low?		?	Marls and silicious sandstones.		
Secondary	Cretaceous		Danian Senonian	Calm and Open Sea	? *Inoceramus Cripsii*, etc.	Sandstones with fucoids, etc.	Westward from Brezoi.	Puchow marls
			Turonian Cenomanian	Very torrential	?	Coarse conglomerates and shingle.	Northward from Vf. Olanesti and Brezoi.	Conglomerates with *Exogyra Columba.*

faces of contact, so that now only an inspection which is at once exhaustive and carried out throughout a large area can reveal the true position of the Cretaceous formations in the Carpathians. After these movements, the sea, which had deposited the Carpathian Flysch, penetrated into the heart of the crystalline region, and took possession of the Brezoi and Titesti Basin. The movements which agitated this region between Tortonian and Eocene times reappear with more intensity at the end of the Oligocene period. At this time probably there arose the Narutu-Cozia anticline, a subsidence with a fault along the north side of the Narutu-Cozia Klippe, also many undulations in the deposits of the Brezoi-Titesti Basin. At the margin of the Carpathian bend the phenomena were more intense; along the present skirt of the mountain an extensive subsidence occurred, forming a geosyncline between Bistrita-Polovragi-Novaci-Bumbesti-Baia de Arama, and Slatioara-Sacel, etc., and also a depression in the Arges-Muscel region. The retreating Flysch sea takes on the character of a Mediterranean Sea in the Olt region, and we have here the same geological and chemical phenomena as in Galicia, Muntenia, and Transylvania, viz., deposition of salt, gypsum, etc.

It would not surprise us if at the south coast of the sea there could have been found the open vents of volcanoes, as is also the case in Transylvania and Servia. These volcanoes could have furnished the ashes and tuffs of the Subcarpathian salt region.

It is noticeable that we have here a bend of the Carpathians just like the one found in eastern Transylvania, which was characterized by volcanic eruptions in this age at the south part of this bend. In the Timoc valley (eastern Servia) dacite and andesite lavas appeared also in that age.

At that time the orographic outlines of the high Carpathians were already fixed. As for the rest of the Roumanian hills and plains region, it probably formed the continuation of the Dobrogean and Bulgarian plateau. The present skirt of the mountains had been uninterruptedly a seashore from the first Mediterranean Sea until the end of Pontic times.

As the southern margin of the sea, we know only that eastward from Sacel a barrier reef developed, identical with that from northern Moldavia and Galicia.

Both at the beginning of and during the Sarmatian age some changes took place in the Olt region; here we find the Lower Sarmatian wanting, there the Upper, and in the higher deposits of the Sarmatian and Mœotic we find gypsum and blocks of palla. The sea also becomes of different character in different parts; in the Olt region subbrackish water, with *Dosinia exoleta* and *Modiola* var. *minora*, predominates; in the west the water becomes fresh, and *Valenciennesia* and *Limnea* appear.

These dislocations are contemporaneous with the large Danube fault; subsequently Pontic waters invaded the hollowed-out ground, forming a lake and depositing layers several hundred meters thick. At this time some volcanic activity made itself felt. The epoch of the most dislocations and folds which are figured in the adjoining map is posterior to the time of *Vivipara bifarcinata*.

After the deposition of the lignite seams, the syncline Rimnicu-Horezu-Piticu became accentuated,[1] between the anticlines Fundatura and Ocnele Mari. In the anticlines many fissures and land-slips have formed. The chief faults are: (1) Dosul-Fundatura-Bujoreni-Runcu; (2) Govora-Maldaresti; (3) Stoenesti-Titireciu-Vladesti-Ramnic; (4) Slatioara with a thrust of the Pontic layers over the folds of the salt formation. As secondary anticline I may note the Buleta-Serbanesti one.

At the same time, the Sacel region became faulted and corrugated, intercalating the anticlines between the mountains and the Slatioara anticline, of which the most important is the southern one. Small the faults can also be recognized (Bircei). The movements, violent in Olt region, are quite reduced in the west, so that, while the Slatioara island is transformed into an unrecognizable "pienine," the Sacel island still retains the character of a true Miocene klippe.

As a long-delayed result of the Mediterranean geosyncline, a stream chose its bed in the Levantine age alongside the skirt of the Carpathians, Gilortu westward, Matru eastward, the deposits from

[1] L. Mrazec (*Bull. Soc. Sc.*, 1900, 1904, etc.) and E. de Martonne (*Comptes Rendus de l'Acad. Sc. Paris*, 1901 and 1904) have described this depression, and especially E. de Martonne first adduced many facts for the tectonic origin of the Subcarpathian depression; my observations, in these adjoining figures and sketch, confirm their suggestion.

which stream can be seen on the eroded hills in the Subcarpathian depression. After this, there occurred in this region small dislocations only, which changed the hydrographic lines,[1] and from this time we have the rivers of Oltenia and the south Carpathian region as we know them at present. This last phenomenon is very important for the orography and hydrography of Oltenia; to this question of paleogeography I intend soon to return.

[1] E. de Martonne has studied this depression exhaustively, and has brought out clearly the last movements of this region and of the whole of Oltenia (*C. R. Ac. Paris*, 1904, etc.).

THE PLEISTOCENE FORMATIONS OF SANKATY HEAD, NANTUCKET[1]

J. HOWARD WILSON
Columbia University

HISTORICAL

The fossiliferous beds at Sankaty Head have been a subject of interest since first reported by Messrs. Desor and Cabot in 1849. The section has been referred to by Professor Shaler[2] as "one of the most important on the New England coast." The beds have been visited and studied by a number of well-known scientists, among whom were Professor A. Hyatt, Mr. C. H. Merriam, and Mr. Sanderson Smith, in 1875; Mr. S. H. Scudder and Mr. Richard Rathbun, a short time afterward; and, still later, Dr. F. J. H. Merrill and Dr. Arthur Hollick. While these investigators have added to the number of species reported from these beds by Messrs Desor and Cabot, they have differed somewhat in their descriptions of the beds, and in their interpretations of the phenomena presented.

The section, when first seen by Messrs. Desor and Cabot, seems, from their description, to have presented very much the appearance shown in Fig. 1, the lower clay forming twenty feet of the lower part of the section and being overlain, apparently unconformably, by the lower sands and gravels. The section at this time was freshly exposed by the cutting of the waves, but for a considerable period of years this cutting has been prevented by the northward extension of the Siasconset apron beach. The face of the bluff at Sankaty Head is now thickly covered with talus, composed of the drift material above the fossiliferous beds, and is in places overgrown with bunches of beech grass (Fig. 2).

[1] Presented to the Faculty of Pure Science in Columbia University as a Thesis for the Degree of A.M.

[2] *Bulletin No. 53*, U. S. Geological Survey, p. 30.

RECENT WORK

During the summer of 1904 the writer made extensive excavations at this point, and exposed a section from the small dunes at the foot of the bluff, to a point several feet above the fossiliferous beds. This work revealed features differing somewhat from those previously recorded, and resulted in the discovery of a number of species which have not heretofore been reported from this point. This paper presents the results of this work, and an interpretation of the phenomena observed.

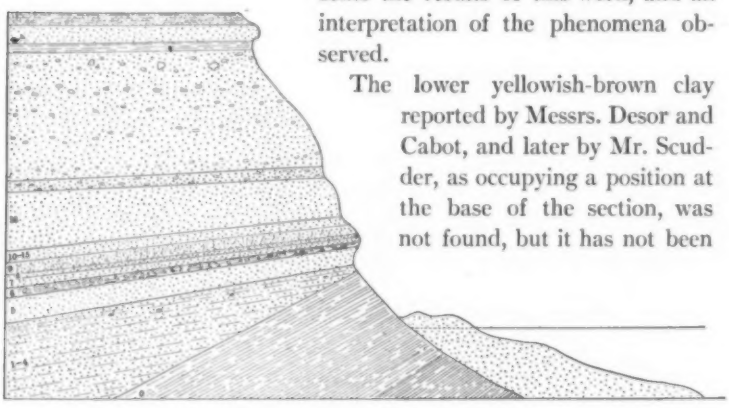


FIG. 1

The lower yellowish-brown clay reported by Messrs. Desor and Cabot, and later by Mr. Scudder, as occupying a position at the base of the section, was not found, but it has not been noticed by any observer since Mr. Scudder's investigations, and its disappearance is no doubt due to its high dip to the southwest, which, joined with the cutting back of the bluff, has caused it to sink below the level of the dune and beach sands, and thus be beyond reach of the ordinary means of excavation. Fig. 3 shows the effect of the cutting on the position of this lower clay. The dotted lines indicate the eroded portion with the clay occupying the position as first reported, while the solid lines represent the bluff approximately as it is today, with the clay hypothetically many feet beneath the dune sands, and perhaps even below sea-level.

No attempt was made to expose the section above the fossiliferous beds which constitute two-thirds or more of the bluff; but as previous investigators have found this to consist of the stratified sands and gravels normal to drift deposits, study was concentrated on the

beds from the base of the bluff to the top of the fossiliferous deposits, and especially on the latter.

LOCATIONS

These Sankaty Head deposits have often proved somewhat difficult to locate on account of the depth of talus which now covers the face of the bluff. Professor F. J. H. Merrill[1] reports them as occurring

FIG. 2

"at a point about three hundred yards south of the lighthouse," and Dr. Arthur Hollick[2] refers to their position as "about a quarter of a mile south" of that structure. It is possible that they extend for some distance along the bluff, appearing at lower and lower levels toward the south, on account of the dip.

The section[3] exposed by the writer was found to be roughly 375 yards south of the lighthouse tower, measured along the top of the bluff. The section is shown in Fig. 4, and described below.

[1] *Transactions of the New York Academy of Science*, Vol. XV (1895–96), p. 11.

[2] *Ibid.*, p. 8.

[3] The fossiliferous beds were located in advance by Miss Elizabeth S. Kite.

DESCRIPTION OF BEDS

No. 1.—Light-gray sand; coarse and fine, more or less stratified and sorted, with light-colored, clayey seams ½ inch thick, which are somewhat ferruginous and hard. The coarse sand grains are rounded, the smaller are more angular and appear fresher. Small pebbles occur, mostly quartz, up to 10^{mm} (rarely 20^{mm}), which are sometimes incrusted with sand grains cemented by iron oxide.

No. 2.—Ferruginous gravel; sand grains varying in size as in the lower bed, the larger rounded, the smaller transparent and mostly angular; some rounded, and most coated with the oxide of iron; mixed with them are small grains of hornblende and magnetite; contains

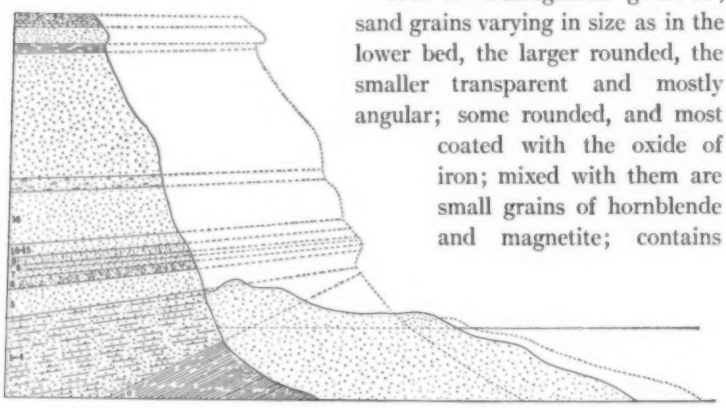


FIG. 3

coarse rounded quartz and other pebbles up to 8^{cm}. In an excavation which was made through the talus 3 or 4 feet south from this point, this 3-inch bed was found to be 1 foot thick, with a base of hard, clayey sand, streaked with reddish-brown and blue clay.

No. 3.—Size of quartz grains uniform with minute grains of hornblende and magnetite. Quartz grains mostly angular, and transparent, ranging up to 3^{mm}; no pebbles; color slightly yellowish.

No. 4.—Ferruginous gravel; coarse and fine sand, and pebbles of quartz and other material up to 25^{mm}, rarely larger; sand and pebbles frequently cemented by iron oxide; pebbles and coarse sand grains well rounded; finest grains of sand angular and transparent; streaks of sand without iron ore are common throughout the bed; grains moderately worn, and quite transparent; larger grains show considerable grinding; black specks throughout, and small pebbles

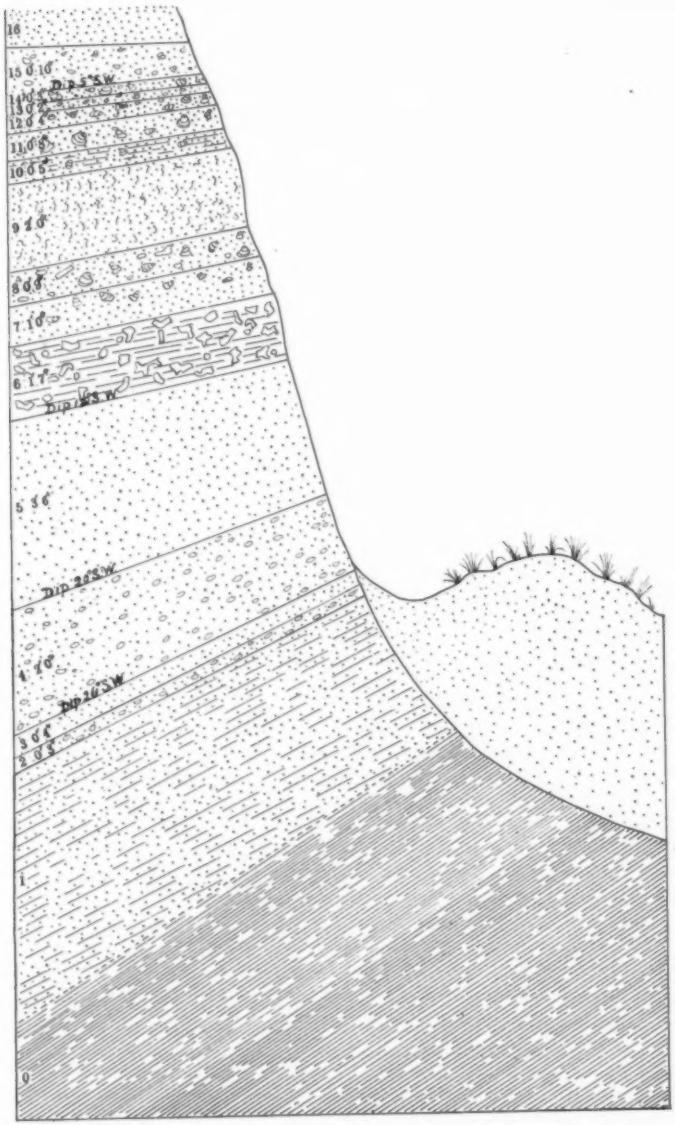

16
15 0 10'
Dip 2° S.W.
14 0
13 0
12 0
11 0 5'
10 0 5'
9 2 0'
8 0 5'
7 1 0'
6 1 1'
Dip 2° S.W.
5 5 6'
Dip 2° S.W.
4 4 0'
Dip 2° S.W.
3 0 0'
2 0 5'
1
0

FIG. 4

up to 15^{mm} occasionally; light-gray and pink grains, the latter garnets, the former probably epidote; material evidently derived from disintegrated granite; minute fragments of shells found?

No. 5.—Almost pure quartz sand, grains varying moderately in size, the smaller angular and transparent, the larger rounded and ground; occasional grains up to 8^{mm}; small black grains, and also dark-green grains of glauconite; occasional garnet fragments, but no pebbles; a few streaks are ferruginated; top of bed, sand fine and angular with numerous black specks. The upper surface shows giant ripple marks in places. Lignite was found in the upper part, some in fine laminæ; one stem-like piece, 20^{mm} in diameter.

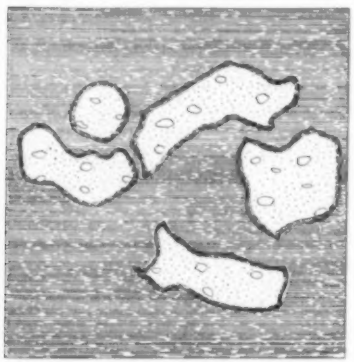


FIG. 5

No. 6.—Begins with a very fine, lutaceous sand, with mica scales and quartz grains, a rock flour with no clay odor. Higher up is blue clay, not very sticky, with faint clay odor, containing much quartz flour; pockets of ferruginous sand, which suggest decayed ferruginous concretions; one concretion found, consisting of a hard, reddish-brown shell, containing coarse ferruginous sand, and small pebbles. This structure is shown in Fig. 5.

No. 7.—Highly ferruginous quartz sand, occasional pebbles, and irregular fragments from the underlying bed. Quartz grains small, mostly rounded, and opaque by iron deposit; minute shell fragments.

No. 8.—Sand of beach type, coarse and fine, the coarse rounded and opaque, the fine angular and transparent, rounded quartz and other pebbles up to 25^{mm}. *Ostrea* extremely abundant, commonly with the valves still together, unworn and unbroken, and with barnacles still adhering to them; *Petricola pholadiformis*, with valves together and erect; *Venus mercenaria*, with valves in contact and held together by the ligament; *Mya arenaria*, with valves together and erect; *Ilyanassa*, minute *Odostomia*, and other delicate shells

occur, none showing wear. Pebbles not numerous, commonly rounded, rarely angular; no clay. This is the so-called "oyster bed."

No. 9.—Quartz sand, with ground-up shell material, and often solid masses of *Serpula dianthus;* fine material, largely fine sand, common among the talus; pebbles, except small ones, not common; no clay or glauconite noticed, but bed hardens on exposure to air. Speciments of *Arca* and *Venus*, with perfectly preserved surface markings occur, many of the latter with valves together, and ligament in place. *Solen*, *Mya*, *Cummingia*, and *Ceronia* also occur with valves together, the two former noticed in their natural upright position. A number of other species occur, and some fine shell fragments. Some shells are perforated by borings and the serpulæ sometimes occur in bunches. This bed is generally referred to as the "serpula bed."

No. 10.—Coarse quartz sand, much water-worn and rounded, many of the grains coated with iron oxide. Pebbles up to 8 ^{cm} common, generally well rounded and largely of quartz; also some fine material of lutaceous character. Shell fragments, and occasionally whole shells, mostly *Venus*, found throughout.

No. 11.—Coarse and fine sand, not well assorted. Pebbles angular or sub-angular, 5–6^{cm}, and even up to 20^{cm}; quartz-porphyry quite common. Shells entire and fragmentary, with *Ostrea* and *Venus* very abundant, the latter of the var. *antiqua*.

No. 12.—Quartz sand of varying grain, full of shell fragments and rounded pebbles, generally small, but some up to 15^{cm}; shells generally fragmentary, but many delicate ones are perfect. Large *Venus*, and well-preserved *Buccinum undatum* fairly common; shell of Mactra removed, leaving a large bunch of barnacles in the bed in the position in which they had been attached to it; bed gray, from fragments of Mytilus.

No. 13.—Reddish, highly oxidized, ferruginous sand with rounded and sub-angular pebbles up to 8 ^{cm}. This is hardly a distinct bed, but is rather a more pebbly and ferruginous layer in Nos. 12 and 14 taken as one bed.

No. 14.—Like No. 12, but more shelly; resembles an uncemented coquina, full of barnacles, in places almost entirely made up of them

(*Balanus portalus*); numerous perfect, small shells and sub-angular pebbles.

No. 15.—Mussel bed; normal beach sand, in places crowded with fragments of *Modiola*, and containing complete small shells of other genera. The mussel shell fragments are generally worn; *Balanus* fragments also common; perfect *Astarte* found, and more or less fragmentary *Lunatia heros*, and *Venus* shells; fossils like those

FIG. 6

found in Nos. 12, 13, 14, but not so numerous. The upper layer is marked by rounded pebbles, generally small, but occasionally 8^{cm} in diameter; pebbles sometimes occur in the mussel layer of lower part of bed. Some of the purer layers of sand are pink, rarely yellow.

No. 16.—Pure quartz sand, of varying grain, stratified and well assorted; grains all rounded and opaque, as if sand had been wind-blown before deposition; some fine streaks, almost like rock-flour, which show as very fine sand grains under microscope, and contain

mica scales; occasional small pebbles up to 6^{mm}; black specks numerous in the finer streaks; rarely a small shell fragment.

The general appearance of the section toward the latter part of the work is presented in Figs. 6 and 7. A close view of the fossiliferous beds is shown in Figs. 8 and 9. No. 8, with the serpula bed above, is shown in Fig. 8, while the beds above, including the lower part of the white drift sands, appear in Fig. 9.

FIG. 7

The upper beds will be referred to now somewhat more collectively, and their more general features described.

No. 10 seems to present some transitorial features from the serpula bed below, while Nos. 11, 12, 13, 14, and 15 have frequently been classed together as the "upper shell bed," although the last has received the special name of the "fragment bed."

In the section exposed, No. 15 seems hardly to be separated as a distinct bed from the bed below, there being no sudden change of character. The shells and shell fragments of No. 14 were found to

extend upward into this so-called "fragment bed," in the form of streaks and pockets, appearing less and less in the upper part.

The proportion of shell material to sand in No. 15, as compared with Nos. 12, 13, and 14, taken as one bed, was found to be considerably less. This would be expected in the resorting of material, the lighter and more soluble shell material being dissolved and borne away, leaving a greater proportion of sand. No. 15, then, has all

FIG. 8

the appearance of being a disturbed and partially assorted portion of the "upper shell bed."

In exposing these beds northward along the bluff, it was found that at a distance of 25 or 30 feet from the section, No. 15 pinches out, while the three beds below have become indistinguishable and their combined thickness is only 9 inches. No. 11 also appeared finer and less shelly, and had increased in thickness to 1 foot, 6 inches. The most noteworthy fact, however, and that which is responsible for the thinning out of these upper beds, is the unconformity of

No. 16, which seems to be the lowermost member of the drift deposits, or its base. So far as the writer knows, this unconformity between the fossiliferous beds and the overlying drift deposits has never before been noticed.

The general phenomena presented by these upper beds are shown in Fig. 10, in which the vertical scale is about three times the horizontal. The thinning of the fragment bed and the unconformity

FIG. 9

between it and the overlying white sands, are also shown in Fig. 9.

FOSSILS

Of the total number of species heretofore reported, only eleven were not found, and are given separately in the following list:[1]

Bryozoa

Membranipora tenuis Desor.
M. catenularia Smelt.
Eschara verrucosa Esper.
Celleporaria incrassata Smith (?)

Gastropoda.

Scala greenlandica Perry.
Eupleura caudata Say.
Cerithiopsis greenii. C. B. Adams.

[1] A *Panopens* has been reported from these beds, but its species not identified.

Pelecypoda.
Arca pexata Say.
Gouldia mactracea Linsley.
Gemma gemma Totten.

Crustacea.
Eupagarus pollicaris Say.

A complete list of the fossils found is given below. A number of species not heretofore reported from this locality were found. It was noticed also that a number of species were not found in the beds

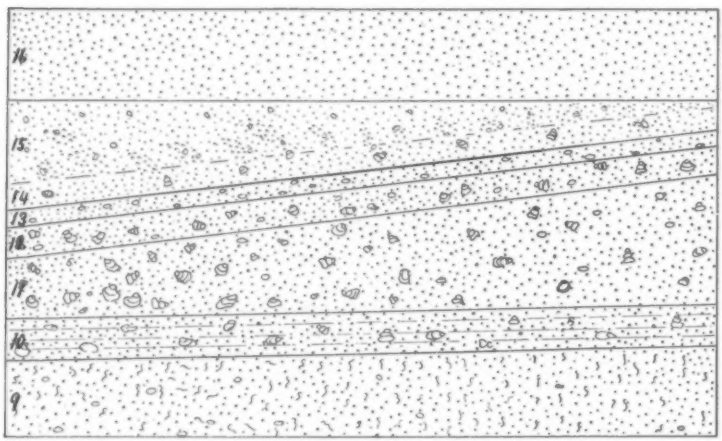


FIG. 10

in which they have been reported as occurring or are more common in some other bed. The writer is of the opinion that many fossils have formerly been collected from the talus, and referred to the wrong bed; for the irregular face of the section, covered with talus, was found at first to be very confusing, and it was not until considerable work had been done that the real nature of the beds, with their sequence and characteristic fossils, was established. Many of the fossils were collected before the work had proceeded far enough to make it possible to say with certainty what beds they came from, but, as far as possible, these will be indicated by their corresponding numbers. The species not before reported from these deposits are indicated by an asterisk.

In the table: x = occurs, a = abundant, c = common, r = rare.

	Number of Bed				
	8	9	10	11	12–15
Porifera.					
Cliona sulphurea Desor	*a*	*x*	*x*	*x*	
Echinodermata.					
					spines
Strongylocentrotus drobachiensis Müll				*x*	*a*
Annelida.					
Serpula dianthus Verrill		*a*	*a*		
Bryozoa.					
Hippothoa variabilis Leidy	?	*a*	*x*	?	*x*
Pelecypoda.					
Arca ponderosa Say			?		
A. transversa Say	*a*	*a*	*a*	*a*	
Venus mercenaria Linn	*a*	*a*	*x*	*x*	*x*
V. mercenaria var. antiqua Verrill		*x*	*x*	*a*	
Ostrea virginiana Lister	*a*	*c*	*a*	*a*	*a*
Anomia aculeata Gmelin					*a*
A. simplex D'Orb					*c*
Mya arenaria Linn	*c*	*c*	*c*	*c*	*x*
M. truncata Linn					few
Mactra solidissima Chemn			one		few
**Serripes laperousii* Deshayes					one
**Pecten magellanicus* Conrad					one
Ensis directus Conrad	*c*	*c*	*c*	*c*	
Corbula contracta Say			*c*		
Mytilus edulus Linn	*x*	*c*	*x*	*x*	*c*
**M. exustus* Linn	few	?			
**Modiola plicatula* Lamk	?	?	?		
M. modiolus Linn					*c*
M. hamatus Verrill	*c*	*x*	*x*		
Crenella glandula Totten					*c*
Macoma fusca Say					few
**M. fusca var. fragilis* Say					one
					?
**M. incongrua von* Martens					one
Cummingia tellinoides Conrad	*c*	*c*	*c*	?	
Petricola pholadiformis Linn	*r*	*r*	*r*		
**Pholas truncata* Say			one		
**Zirfaea crispata* Linn					one
Panopea arctica (Lamk.) Gould (=*Saxicava norvegica* Linn.)					frag.
Saxicava arctica Linn					*c*
Pandora gouldiana Dall					*r*
					two
**P. crassidens* Conrad					valves
Astarte quadrans Gould					*a*
Astarte undata Gould					*r*
A. castanea Say					*a*
**A. crebricostata* Forbes					*r*
Ceronia deaurata Turton (=*Mesodesma*)					few
C. arctata Adams					*c*

	Number of Bed				
	8	9	10	11	12–15
Venericardia (*Cyclocardia*) *borealis* Conrad....					few
V. novangliae Morse.....					*c*
Thracia truncata Migh. and Adams.....					few
Gastropoda.					
Odostomia impressa Say.....	*a*	*x*	?	?	
O. trifida Gould	*a*	*x*	few	few	
Turbonilla interrupta Totten.....	*r*				
Ilyanassa obsoleta Say.....		*x*	few		
I. trivittata Say.....					*c*
Urosalpinx cinerea (Say).....	*r*	*c*	*r*	*r*	*r*
**Bittium negrum* Totten.....	*r*				
Cingula (*Rissoa*) *aculeus* Gould.....					*r*
**C. latior* Migh. and Adams.....					one
**Cerithiopsis terebralis* Adams.....					one
Skenea planorbis Forbes and Hanley.....					*r*
Margarita (*Solaricella*) *obscura* Couth.....					frag.
**M. undulata* Sowerby.....					one
**Fasciolaria ligata* Migh. and Adams.....					one
Tritonofusus stimpsoni Mörch.....					*c*
**Fusus tonatus* Gould.....					frag.
**Chrysodomus stonei* Pilsby.....					one
Buccinum undatum Linn.....					*c*
**Sipho islandicus?* Linn.....					frag.
Trophon scalariformis? Gould.....					*r*
Lunatia heros Say.....					*c*
L. triseriata Say.....					*c*
Neverita duplicata Say.....					one
**Littorina palliata* Gould.....					one
Astyris lunata Dall.....				*c*	
Caecum pulchellum Stimpson.....					*r*
Diodora noachina Gray.....					*r*
Crucibulum striatum Say.....					*r*
Crepidula fornicata Lamk.....	*c*	*a*	*c*	*c*	
Crepidula convexa Say.....	*c*	*c*	*c*	*x*	
C. plana Say.....	*c*	*c*	*c*	?	?
Crustacea.					
Balanus crenatus Brug.....					*c*
B. eburneus Gould.....	*c*	*c*	*c*		
B. porcatus Da Costa.....					*a*
**Eupanopeus herbsti* Milne-Edwards.....		*a*			one worn claw
**Neopanope texana sayi* Smith.....		*c*			
**Callinectes sapidus* Rathbun.....		one claw			

It will be noticed that twenty-one species new to this locality were collected. Of these a number were identified by Dr. W. H. Dall. The crab fragments were identified by Miss Mary J. Rathbun. The identification of *Serripes laperousii* Deshayes, *Macoma incongrua* von

Martens, and *Pandora crassidens* Conrad, was a surprise, as the first two belong to the arctic fauna of the Pacific coast and, according to Dall, have not heretofore been found east of Point Barrow, while the last is common in the Miocene of Maryland, and, according to the same authority, has not previously been found above that horizon. It does not seem possible that the *Pandora* could have been derived from an older bed, as all the other species are distinctly Pleistocene; and in case the material from an older bed had been disturbed and redeposited, we should expect to find a number of associated species. Moreover, the two left valves found were entirely free from any trace of an old matrix, were no more worn than the other fossils from the same bed, and were of the same color and general appearance. It would seem, then, that *Pandora crassidens* Conrad has in some localities continued on into Pleistocene times. The two Pacific species would seem to indicate that in Pleistocene times the "Northwest Passage" was more open than at present, and perhaps also that in the interglacial period in which these beds were deposited the ice had entirely disappeared from even the northern part of the continent, so as to leave the channels along the coasts of that region free from ground ice.

A single specimen of the rare species *Chrysodomus stonei* Pilsbry was found, which was first reported and described from specimens washed ashore from supposed Pleistocene beds under the sea, off the southern coast of New Jersey. This, and the Miocene *Pandora*, are the only species yet found occurring in these beds which are now extinct.

It has been a matter of comment, that not a single *Pecten* has heretofore been found at this locality in beds furnishing in abundance such species as *Ostrea virginica*, *Venus mercenaria*, and *Mya arenaria*. In looking over a quantity of material from the "upper shell bed," a two-inch shell fragment was found which seems to be clearly identified as from near the ventral margin of a specimen of our northern species, *Pecten magellanicus* Conrad.

Modiola hamatus Verrill is mentioned in former reports as common in the "lower shell bed," and was found in association with *Mytilus exustus* Linn, from which at times it is difficult to distinguish. It is probable that the latter species has been mistaken for *Modiola*

hamatus by collectors from this locality, and all listed under the latter name.

In regard to the position in the section of *Venus mercenaria* var. *antiqua* Verrill, previous reports mention it as abundant in the "lower shell bed," but not found above this horizon. The writer found, on the contrary, that the most typical forms occurred only above the serpula bed, in No. 11, while forms less typical, and more intermediate between it and the common species, were found in the serpula bed. In this case, the name *antiqua* would be somewhat of a misnomer, as the variety would seem to represent simply a short lived mutation from the common species.

The *Astartes* as a group are very variable, presenting some puzzling differences within what may be considered a single species. Several species occur in the Sankaty deposits, and a small form which occurs very abundantly in the upper beds (over two hundred being collected), seems to have been identified in the past as *Astarte quadrans* Gould; but of the great number collected, the one which approaches nearest to *A. quadrans* of Gould seems to be identical with the variety *portlandica* of Mighels, the others differing from *A. quadrans* in a line of development far beyond even *A. portlandica*.

A number of the Sankaty Head forms are shown in Fig. 11, Nos. 6–15, while several *A. castanea* from the same locality are figured in Nos. 1–5 for comparison. The whole series of *A. quadrans* differs from *A. castanea* in their small size, excentric position of the beaks, the nearly straight anterio-dorsal margin, the absence of the broad, slightly elevated bands of growth sometimes found in *A. castanea*, and the fact that the latter has a much heavier shell, with very much higher hinge area and stronger teeth.

In the figures shown, No. 14 is almost identical with Gould's figure of *A. portlandica*, and is considered here as representing the type of that species. Most of the other forms figured, however, seem to show specific differences, being much higher and having the beaks much more excentrically situated, and should perhaps be separated as a distinct species, for which the name *sankatyensis* is proposed.

Nos. 7–12 exhibit very well this great divergence from the type of *A. portlandica*, while Nos. 6, 13, and 15 are intermediate types.

A. portlandica at the present time is more limited in its range than *A. quadrans*, and is somewhat rare.

From the fact that *A. sankatyensis* occurs only in the "upper shell bed," where it is quite common and associated with arctic species, it seems probable that it has a very northern range, or is a form which has died out, and is not represented among recent shells.

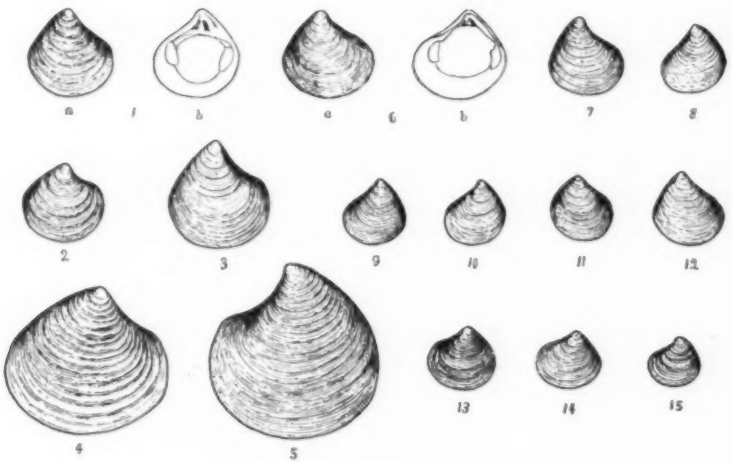


FIG. 11

INTERPRETATION

It has been thought that these fossiliferous beds at Sankaty Head were made up of old material redeposited; that the last or Wisconsin ice-sheet, moving across the sea-floor, had torn up and transported a quantity of material from old beds lying beneath the sea, and redeposited it in the present position near the ice margin. A notable case of this kind is found in the deposits containing marine fossils which are found on the flanks of Mount Snowdon in Wales, and which owe their elevated situation to the movement of the great Irish Sea glacier over the bed of that sea, and the crowding of its front with its morainal accumulations up onto the highlands of northwestern Wales.

It may be mentioned in this connection that the line of kame hills

of which Sankaty Head is the eastern extension do not represent the southern limit of the ice-sheet at this point. It was found that the ice maintained a quite stationary front some three miles farther to the south, forming the well-developed contact slope which runs in a northwesterly direction from Tom Never's Head.

The writer held the same opinion in regard to these Sankaty Head deposits at the beginning of the work, the beds at that time presenting a very confused appearance, which was found later to be due to a superficial disturbance with a mingling of talus. When the disturbed portion was finally removed, however, the beds were found to present very characteristic and constant characters. That these beds could not owe their origin to glacial action, but are normal marine deposits, seems to be certain for the following reasons: (1) Numerous delicate, perfect, and unworn shells occur. (2) Numerous bivalves, already mentioned in the description of the beds, were found in the natural position in which they lived, with both valves together, and, in the case of *Venus*, with even the ligament in place. (3) There is no mixture of faunas, as would be the case in the redeposition of material from different beds. The three lower beds contain fossils which have a distinctly southern range, and are of a shallow water type; while the upper beds contain a decidedly northern fauna, many species being characteristic of arctic seas, and of considerably deeper water. Such conditions can hardly be explained except by supposing these beds to be in their original positions.

In view of the phenomena observed, and the facts ascertained in regard to these deposits, it would seem that an attempt might be made toward an explanation of their history. The lower clay noticed by early observers is probably identical with the yellowish-brown clay found elsewhere on the island, generally more or less covered by the glacial drift. This clay is apparently an old till of pre-Wisconsin age, and which, modified by erosion, formed the land surface of hills and valleys in this region before the advance of the last ice-sheet, which buried it under a heterogeneous mass of drift. At this time shallow inlets probably occupied some of the low areas between the higher land surfaces, or lagoon-like bays were to be found at points along this old shore, protected from the open sea by bars or low barrier beaches.

The Sankaty Head deposits seem to be best accounted for as having accumulated in one of these inlets or lagoons. The lower beds were undoubtedly deposited in a shallow body of water connected with, but well protected from, the open sea. This is well shown by the prevalence of such species as *Ostrea*, *Venus*, and *Mya*, and especially numerous specimens of mud crabs, and the presence of our edible crab, *Callinectes sapidus* Rathbun, which is found today in some of the little creeks connected with the harbor on the north side of the island.

Although the total thickness of the fossiliferous beds is but 8 feet a great difference is found between the lower and upper beds, showing changes in the physical conditions. At the time of deposition of the upper beds, the waters had become much colder, probably due to the return of glacial conditions, the fossils being chiefly of the northern fauna driven southward in front of the advancing ice-sheet. The fossils, besides being more northern, and in some instances even arctic, in their range, are also of species which are generally found in somewhat deeper water.

A noticeable unconformity is found between the fossiliferous beds and the overlying 10 feet of white sand (No. 16) at the point where the section was exposed, as shown in Fig. 10. These sands are very pure, and are finely stratified and assorted, the bedding being nearly horizontal. The sand grains are mostly well-rounded and worn, and at rare intervals, minute fragments of shells occur. In fact this bed, to all appearances, seems to consist of wind-blown sand derived from dunes which have been destroyed and redeposited.

It will be noticed also from the general section, Fig. 4, that there has been a gradual decrease of dip from the lowest of the beds exposed, to the uppermost of the fossiliferous beds, above which the unconformity occurs.

The upper fossiliferous beds, with their change of fauna, the apparent unconformity above, and the overlying white sands, show changes in the physical conditions which require special explanation.

There seem to be but two hypotheses which are at all applicable to the facts, and while the phenomena can hardly be reconciled to one, it will be given first, and the points wherein it fails to satisfy the conditions will be explained. The first hypothesis may be stated as follows:

After the lower beds were deposited, and the Wisconsin ice-sheet had attained considerable extension, the land began to subside as the ice advanced, while a deeper water fauna, of arctic type, driven southward by the advancing ice, lived in the region, and its shells were imbedded in the upper beds. As the ice reached Nantucket, the pressure of its front against obstructing surfaces produced a crumpling or folding of the strata, as has been observed in other regions, such as shown in Fig. 12. This folding would account for the gradual increase of dip from the top to the bottom of the section at the point indicated by the diagonal line *AB*, representing the face of the bluff in Fig. 12. After the folding had taken place, the barrier beach brought below sea-level by the subsidence of the region, was destroyed by wave-action and redeposited as the upper white sands. As the Wisconsin ice-sheet reached and passed beyond this point, it is likely that a portion of these sands was removed; but soon deposition of glacial material began to take place, and these beds were buried under the vast amount of kame sands and gravel which form the upper part of the bluff.

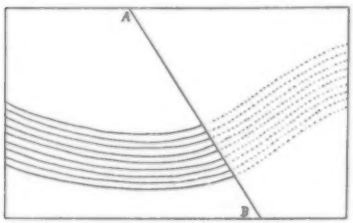


FIG. 12

This hypothesis seems to fail in the following particulars: (1) It seems improbable that the difference in dip can be accounted for in the way mentioned, because (*a*) the earliest reports on the dip of the various beds agree almost exactly with present observations, while a cutting back of the bluff, such as has taken place since the locality was first visited, should show a very different dip for the same beds as will be seen from a study of Fig. 12; and (*b*) the lateral pressure sufficient to produce this folding would be indicated by minor crumplings of the tough upper clay (No. 6), but, so far as observed, these crumplings do not occur. (2) In order to produce the folding, we must assume the ice-front to have been in the immediate vicinity, which assumption cannot be reconciled with the deposition of the upper white sands, which are of seaward origin, very pure and unmixed with any such heterogeneous material as could not fail to be present in proximity to the ice-front.

This theory, then, in its entirety, cannot be reconciled to the facts, and must be modified in some particulars.

The following hypothesis is presented as being in accord with all the phenomena observed, and probably coming nearest to the truth in an exposition of the history of these deposits:

At the beginning of this deposition, a precipitous shore probably stood to the north of the lagoon, or the lagoon itself may have been in the nature of a basin-shaped inlet, open to the south, and surrounded by steep shores of which the deeply dipping lower clay formed the portion below sea-level. A variety of material derived from this old shore by the encroaching sea before the outer bar was formed, was spread over the bottom of the basin, assuming nearly the dip of the surface upon which it was deposited, the dip becoming less and less as the basin became filled. This agrees with the coarse nature of the lower deposits, and the irregular bedding noticed. One of the lower ferruginous gravels (No. 2) was found to increase from 3 inches to 1 foot in thickness within a distance of 3 or 4 feet to the south. The dip is in the nature of a false dip, the deposits resembling very much in structure those fan-like non-marine accumulations in which the dip decreases in passing upward through the successive layers. We may consider then that the dip is an initial one, and not caused by a subsequent folding of the strata.

The lower white sands (No. 5) probably represent the washing in of some seaward material, and giant ripple marks, such as would be made by ocean waves, were found on the upper part. The lignite found in this bed is no doubt derived from seaweed and driftwood.

The lagoon or inlet now became well protected from the open sea by the development of the outer bar or barrier beach, and the upper clay of No. 6 became deposited from landward washings, on the floor of the lagoon. This now became the home of shoal water animals, as evidenced by the species which have already been enumerated. How long these conditions lasted it is of course impossible to tell, but they were brought to an end before the deposition of the upper beds. As these upper beds were formed, a subsidence of the land in this region was taking place, and no doubt connected with the advance of the huge mass of the Wisconsin ice-sheet. The water became colder, the southern fauna was driven out, and deeper-water northern, and even arctic species were present, and included in the

deposits. As the subsidence continued, the barrier beach, unable to hold its own, allowed the seas to break into the lagoon, causing a disturbance of the upper deposits, the formation of the fragment bed, and the unconformity. Finally this outer bar became destroyed, and the material of which it was composed was washed into the lagoon, forming the upper white sand (No. 16).

The next event which took place was the advance of the Wisconsin ice-sheet over and beyond this region, eventually burying the deposits under 50 feet or more of drift. This last advance of the great continental glacier may have pushed its front some distance to the south of Nantucket, during which time, and during its retreat to the position in which the Nantucket terminal moraine was formed, or during the first part of this Nantucket stage, a re-elevation of the land to its present position must have taken place.

At any rate, from evidence gathered all over the island we know that the land stood not far from its present level when the ice-front occupied the Nantucket position. There is absolutely no evidence to show that the Nantucket moraine, with its apron plain and other characters, was formed below sea-level, or at any elevation essentially different from that which it occupies at the present day.

EDITORIAL.

The growing importance of economic geology finds a fitting expression in the establishment of a journal of high grade devoted especially to its interests, under the editorial direction of John Duer Irving, with Waldemar Lindgren, James Furman Kemp, Frederick Leslie Ransome, Heinrich Ries, Marius R. Campbell, and Charles Kenneth Leith as associate editors—a staff that is at once a guarantee of the new journal's high purposes and of its complete scientific control. It takes the title *Economic Geology*, and is to be a semi-quarterly. It pays this *Journal* the compliment, for which we bow our acknowledgments, of taking a similar form as well as a like period of publication. It starts with an October-November number containing a very attractive table of contents, consisting of "The Present Standing of Applied Geology," by Frederick Leslie Ransome; "Secondary Enrichment in Ore-Deposits of Copper," by James Furman Kemp; "Hypothesis to Account for the Transformation of Vegetable Matter into the Different Varieties of Coal," by Marius R. Campbell; "Ore-Deposition and Deep Mining," by Waldemar Lindgren; "Genesis of the Lake Superior Iron Ores," by Charles Kenneth Leith; and "The Chemistry of Ore-Deposition—Precipitation of Copper by Natural Silicates," by Eugene C. Sullivan; with an editorial by Irving, and Discussions, Reviews, Recent Literature on Economic Geology, Scientific Notes, and News.

It will be noted that the initial papers, chiefly by members of the editorial staff, treat of subjects of the higher order of importance, and this may doubtless be taken to foreshadow future lines of editorial endeavor. There is a notable tendency to strike at radical facts, or at underlying principles and hypotheses—a welcome feature. No less than in other fields of geology is there present need for radical treatment of economic problems. This is true not more on the economic side, in the narrow sense of the term, than on the scientific and philosophic side. Probably the greatest contribution that can now be made to applied geology is the development of the underlying

principles of that portion of scientific and philosophic geology that is applicable to formations of industrial value. Contributions to this may be sought, as has been the endeavor of this *Journal*, through attempts to develop the basal science and philosophy upon which all formations depend, or it may be sought by a more selective effort, such as the new journal essays.

We extend cordial greetings to our new colleagues and wish them the success we are sure they will merit. There is a peculiar personal pleasure in extending a managing editor's welcome to the son of Roland Duer Irving, our most intimate geological friend and colleague during the years of youthful endeavor to find a place among geological workers.

T. C. C.

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